JOURNAL AND PROCEEDINGS

OF THE

ROYAL SOCIETY

OF NEW SOUTH WALES

FOR

1955

(INCORPORATED 1881)

VOLUME LXXXIX

Part I-IV

EDITED BY

F. N. HANLON, B. Sc., Dip. Ed.

Honorary Editorial Secretary

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PART I (pp. i-xxviii and 1-84)

OF

VOL. LXXXIX

Containing List of Members, Report of the Council, Balance Sheet,
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in April and May, with Plates I-II

EDITED BY

F. N. HANLON, B.Sc., Dip.Ed.

Honorary Editorial Secretary

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Part I

Royal Society of New South Wales

OFFICERS FOR 1955-1956

Patrons:

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M. R. LEMBERG, D.Phil., F.R.S.

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J. S. PROUD, B.E., M. (*Aust.*), I.M.M., A.M.I.E.

GRIFFITH TAYLOR, D.Sc., B.E., B.A.

A

NOTICE.

THE ROYAL SOCIETY of New South Wales originated in 1821 as the " Philosophical Society of Australasia " ; after an interval of inactivity, it was resuscitated in 1850, under the name of the " Australian Philosophical Society ", by which title it was known until 1856, when the name was changed to the " Philosophical Society of New South Wales " ; in 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, it assumed its present title, and was incorporated by Act of the Parliament of New South Wales in 1881.

TO AUTHORS.

Particulars regarding the preparation of manuscripts of papers for publication in the Society's Journal are to be found in the " Guide to Authors", which is obtainable on application to the Honorary Secretaries of the Society.

FORM OF BEQUEST.

I bequeath the sum of £   to the ROYAL SOCIETY OF NEW SOUTH WALES, Incorporated by Act of the Parliament of New South Wales in 1881, and I declare that the receipt of the Treasurer for the time being of the said Corporation shall be an effectual discharge for the said Bequest, which I direct to be paid within   calendar months after my decease, without any reduction whatsoever, whether on account of Legacy Duty thereon or otherwise, out of such part of my estate as may be lawfully applied for that purpose.

[*Those persons who feel disposed to benefit the Royal Society of New South Wales by Legacies are recommended to instruct their Solicitors to adopt the above Form of Bequest.*]

The volumes of the *Journal and Proceedings* may be obtained at the Society's Rooms, Science House, Gloucester Street, Sydney.

Volumes XI to LXVIII (1877–1934)
LXX (1936)
LXXII (1938)

and subsequent issues.

Volumes I to X (to 1876) and LXIX and LXXI are out of print.

LIST OF THE MEMBERS

OF THE

𝔯𝔬𝔶𝔞𝔩 𝔖𝔬𝔠𝔦𝔢𝔱𝔶 𝔬𝔣 𝔑𝔢𝔴 𝔖𝔬𝔲𝔱𝔥 𝔚𝔞𝔩𝔢𝔰

as at April 1, 1955

P Members who have contributed papers which have been published in the Society's Journal. The numerals indicate the number of such contributions.

‡ Life Members.

Elected.			
1944			Adamson, Colin Lachlan, Chemist, 36 McLaren-street, North Sydney.
1938	P	2	‡Albert, Adrien, D.SC., PH.D. *Lond.*, B.SC. *Syd.*, F.R.I.C. *Gt.B.*, Professor of Medical Chemistry, The Australian National University, 183 Euston-road, London, N.W.1.
1935			‡Albert, Michael Francois, " Boomerang," Billyard-avenue, Elizabeth Bay.
1950			Alexander, Albert Ernest, B.SC., M.A., PH.D., Professor of Chemistry, N.S.W. University of Technology ; p.r. 178 Raglan-street, Mosman.
1941			‡Alldis, Victor le Roy, I.S., Registered Surveyor, Box 57, Orange, N.S.W.
1948			Anderson, Geoffrey William, B.SC., c/o Box 30, P.O., Chatswood.
1948	P	2	Andrews, Paul Burke, 5 Conway-avenue, Rose Bay.
1930	P	1	Aston, Ronald Leslie, B.SC., B.E. *Syd.*, M.SC., PH.D. *Camb.*, A.M.I.E. *Aust.*, Senior Lecturer in Civil Engineering and Surveying in the University of Sydney ; p.r. 24 Redmyre-road, Strathfield. (President, 1948.)
1919	P	1	‡Aurousseau, Marcel, B.SC., c/o Royal Geographical Society, Kensington Gore, London, S.W.7.
1924	P	2	Bailey, Victor Albert, M.A., D.Phil., F.Inst.P., Professor of Experimental Physics in the University of Sydney.
1934	P	2	Baker, Stanley Charles, M.SC., A.Inst.P., Head Teacher of Physics, Newcastle Technical College, Tighe's Hill ; p.r. 8 Hewison-street, Tighe's Hill, N.S.W.
1937			Baldick, Kenric James, B.SC., 19 Beaconsfield-parade, Lindfield.
1951			Banks, Maxwell Robert, B.SC., Lecturer in Geology, University of Tasmania, Hobart, Tasmania.
1919			‡Bardsley, John Ralph, 29 Walton-crescent, Abbotsford.
1951			Basden, Keith Spencer, B.SC., A.S.T.C., School of Mining and Applied Geology, N.S.W. University of Technology, Box 1, P.O., Kensington.
1950			Baxter, John Philip, B.SC., PH.D., A.M.I.chem.E., Vice-Chancellor and Professor of Chemical Engineering, N.S.W. University of Technology, Broadway, Sydney.
1947			Beckmann, Peter, A.S.T.C., Lecturer in Chemistry, Technical College, Wollongong.
1933			Bedwell, Arthur Johnson, Eucalyptus Oil Merchant, " Kama," 10 Darling Point-road, Edgecliff.
1926			Bentivoglio, Sydney Ernest, B.SC.Agr., 42 Telegraph-road, Pymble.
1937	P	7	Birch, Arthur John, M.SC., D.Phil. *Oxon.*, Professor of Organic Chemistry, University of Sydney, Sydney.
1920			‡Bishop, Eldred George, Manufacturing and General Engineer, 37-45 Myrtle-street, Chippendale ; p.r. 26A Wolseley-road, Mosman.
1948			Blanks, Fred Roy, B.SC. (Hons.), Industrial Chemist ; p.r. 10 Glenwood-avenue, Coogee.
1946			Blaschke, Ernest Herbert, 6 Illistron Flats, 63 Carrabella-street, Kirribilli.
1933	P	30	Bolliger, Adolph, PH.D., F.R.A.C.I., Director of Research, Gordon Craig Urological Research Laboratory, Department of Surgery, University of Sydney. (President, 1945.)
1951	P	1	Booker, Frederick William, M.SC., PH.D., Government Geologist, c/o Geological Survey of N.S.W., Mines Department, Sydney.
1954			Booth, Brian Douglas, PH.D., B.SC., A.R.I.C. ; p.r. 29 March-street, Bellevue Hill.

Elected.

1920	P 9	‡Booth, Edgar Harold, M.C., D.Sc., F.Inst.P., "Hills and Dales," Mittagong. (President, 1936.)
1951	P 1	Bosson, Geoffrey, M.Sc. *Lond.*, Professor of Applied Mathematics, N.S.W. University of Technology, Broadway, Sydney.
1939	P 26	Bosworth, Richard Charles Leslie, M.Sc., D.Sc. *Adel.*, Ph.D. *Camb.*, F.R.A.C.I., F.Inst.P., c/o C.S.R. Co. Ltd., Sydney ; p.r. 52 Beechworth-road, Pymble. (President, 1951.)
1946	P 1	Breyer, Bruno. M.D., Ph.D., M.A., F.R.A.C.I., Senior Lecturer in Agricultural Chemistry, Faculty of Agriculture, The University of Sydney.
1952		Bridges, David Somerset, Schoolteacher, 19 Mt. Pleasant-avenue, Normanhurst.
1919	P 1	‡Briggs, George Henry, D.Sc., Ph.D., F.Inst.P., Officer-in-Charge, Section of Physics, National Standards Laboratory of Australia, University Grounds, Sydney ; p.r. 13 Findlay-avenue, Roseville.
1942		Brown, Desmond J., M.Sc. *Syd.*, Ph.D. *Lond.*, D.I.C., Department of Medical Chemistry, Australian National University, 183 Euston-road, London, N.W.1.
1945		Brown, Norma Dorothy (Mrs.), B.Sc., Biochemist, 23 Dobroyd Parade, Dobroyd Point.
1935	P 11	Browne, Ida Alison, D.Sc. ; p.r. Mount Stewart Flats, 363 Edgecliff-road, Edgecliff. (President, 1953.)
1913	P 23	‡Browne, William Rowan, D.Sc., Mount Stewart Flats, 363 Edgecliff-road, Edgecliff. (President, 1932.)
1952		Bryant, Raymond Alfred Arthur, A.S.T.C., A.M.I.E.Aust., A.M.I.Loco.E., Companion R.Ae.S., Lecturer in Mechanical Engineering, N.S.W. University of Technology ; p.r. 32 Bruce-street, Brighton-le-Sands.
1947		Buchanan, Gregory Stewart, B.Sc. (Hons.), Lecturer in Physical Chemistry, Sydney Technical College ; p.r. 19 Ferguson-avenue, Thornleigh.
1940		Buckley, Lindsay Arthur, B.Sc., 29 Abingdon-road, Roseville.
1946	P 1	Bullen, Keith Edward, M.A., Ph.D., Sc.D., F.R.S., Professor of Applied Mathematics, University of Sydney, Sydney, N.S.W.
1898		‡Burfitt, W. Fitzmaurice, B.A., M.B., Ch.M., B.Sc. *Syd.*, F.R.A.C.S., "Radstoke," Elizabeth Bay.
1952	P 2	Burke-Gaffney, Rev. Thomas Noel, S.J., Director, Riverview College Observatory, Riverview, N.S.W.
1950		Burton, Gerald, B.Sc. *Syd.*, Geologist, c/o Bureau of Mineral Resources, Canberra, A.C.T.
1950		Caldwell, John Henry, B.Sc. *Syd.*, 63 Arthur-street, Homebush.
1938	P 2	‡Carey, Samuel Warren, D.Sc., Professor of Geology, University of Tasmania, Tasmania.
1945		Carter, Harold Burnell, B.V.Sc., Agricultural Research Council of Great Britain, Edinburgh, Scotland.
1944		Cavill, George William Kenneth, M.Sc. *Syd.*, Ph.D. *Liverpool*, Senior Lecturer, Organic Chemistry, N.S.W. University of Technology ; p.r. "Alwilken," Coral-road, Cronulla.
1954		Chaffer, Edric Keith, Tanner, 27 Warrane-road, Roseville.
1933		Chalmers, Robert Oliver, A.S.T.C., Australian Museum, College Street, Sydney.
1940		Chambers, Maxwell Clark, B.Sc., c/o Coty (England) Ltd., 35-41 Hutchinson-street, Moore Park ; p.r. 58 Spencer-road, Killara.
1952		Chapman, Dougan Wellesley, Surveyor, 3 Orinoco-street, Pymble.
1951		Charlwood, Joan Marie, B.Sc., Biochemist, 184 Queen-street, Concord West.
1953		Christie, Thelma Isabel, B.Sc., Chemistry School, N.S.W. University of Technology ; p.r. 181 Edwin-street, Croydon.
1935	P 2	Churchward, John Gordon, B.Sc.Agr., Ph.D., 1 Hunter-street, Woolwich.
1940		Cohen, Samuel Bernard, M.Sc., A.R.A.C.I., 74 Boundary-street, Roseville.
1940	P 2	Cole, Edward Ritchie, B.Sc., 7 Wolsten-avenue, Turramurra.
1940	P 1	Cole, Joyce Marie, B.Sc., 7 Wolsten-avenue, Turramurra.
1948		Cole, Leslie Arthur, A.A.S.A., Secretary, Robert Corbett Pty. Ltd., Lane Cove ; p.r. 21 Carlisle-street, Rose Bay.
1940		Collett, Gordon, B.Sc., 27 Rogers-avenue, Haberfield.
1948		Cook, Cyril Lloyd, M.Sc., Ph.D., c/o Propulsion Research Laboratories, Box 1424H, G.P.O., Adelaide.
1946		Cook, Rodney Thomas, A.S.T.C., 10 Riverview-road, Fairfield.
1945		Coombes, Arthur Roylance, A.S.T.C. (Chem.), 14 Georges River-road, Croydon.
1913	P 5	‡Coombs, F. A., F.C.S., Instructor of Leather Dressing and Tanning, Sydney Technical College ; p.r. Bannerman-crescent, Rosebery.

Elected.

1933		Corbett, Robert Lorimer, Scot Chambers, Hosking-place, Sydney.
1940		Cortis-Jones, Beverly, M.SC., 62 William-street, Roseville.
1919		‡Cotton, Frank Stanley, D.SC., Lisgar-road, Hornsby.
1909	P 7	‡Cotton, Leo Arthur, M.A., D.SC., Emeritus Professor of Geology, Sydney University ; 113 Queen's Parade East, Newport Beach. (President, 1929.)
1941	P 1	Craig, David Parker, PH.D., Professor of Physical Chemistry, University of Sydney.
1921	P 1	‡Cresswick, John Arthur, A.R.A.C.I., F.C.S., Production Superintendent and Chief Chemist, c/o The Metropolitan Meat Industry Commissioner, State Abattoir and Meat Works, Homebush Bay ; p.r. 101 Villiers-street, Rockdale.
1954	P 1	Crook, Keith Alan Waterhouse, B.SC., Geology Department, University of Sydney ; p.r. 7 Kylie-avenue, Killara.
1948		Cymerman-Craig, John, PH.D., D.I.C., A.R.C.S., B.SC., A.R.I.C., Lecturer in Organic Chemistry, University of Sydney.
1940		Dadour, Anthony, B.SC., 25 Elizabeth-street, Waterloo.
1951		Darvall, Anthony Roger, M.B., B.S., D.O., Medical Practitioner, Royal Prince Alfred Hospital, Missenden-road, Camperdown.
1952		Davies, George Frederick, A.M.I.E.T. *Britain*, Engineer, 57 Eastern-avenue, Kingsford.
1952		Davison, Clem Newton, A.S.T.C., B.E. (Mining Engineering), c/o Territory Enterprises Pty. Ltd., Rum Jungle, N.T.
1952		Day, Alan Arthur, B.SC., 13 Besborough-avenue, Bexley.
1952		Debus, Elaine Joan, Chemist, 62 Tarrant's-avenue, Eastwood.
1953		de Lepervanche, Beatrice Joy, 29 Collins-street, Belmore.
1928		Donegan, Henry Arthur James, M.SC., A.S.T.C., A.R.A.C.I., A.R.I.M.M., Senior Analyst, Department of Mines, Sydney ; p.r. 18 Hillview-street, Sans Souci.
1947		Downes, Alan Marchant, B.SC., Chemistry Department, University of Melbourne, Carlton, N.3.
1950		Drummond, Heather Rutherford, B.SC., 15 Watson-street, Neutral Bay.
1937	P 15	Dulhunty, John Allan, D.SC., Geology Department, University of Sydney ; p.r. 40 Manning-road, Double Bay. (President, 1947.)
1948		Dunlop, Bruce Thomas, B.SC., Schoolteacher, 77 Stanhope-road, Killara.
1951		Dunn, Thomas Melanby, B.SC., c/o Chemistry Department, University College, Gower-street, London, W.C.1.
1924		Dupain, George Zephirin, A.R.A.C.I., F.C.S., Director Dupain Institute of Physical Education and Medical Gymnastics, Manning Building, 449 Pitt-street, Sydney ; p.r. 15 Calvert-parade, Newport Beach.
1934	P 58	Dwyer, Francis P. J., D.SC., Senior Lecturer in Chemistry, University of Sydney, Sydney.
1945		Eade, Ronald Arthur, M.SC. *Syd.*, PH.D. *Liverpool,* Senior Lecturer, Organic Chemistry, N.S.W. University of Technology, Broadway, Sydney.
1951		Edgar, Joyce Enid (Mrs.), B.SC., 16 Cooper-street, Cessnock.
1950		Edgell, Henry Stewart, c/o Richfield Oil Corporation, 5900 Cherry-avenue, Long Beach, California.
1946	P 1	El Nashar, Beryl, B.SC., PH.D., DIP.ED. ; p.r. 23 Morris-street, Mayfield West, 2.N, N.S.W.
1934	P 2	Elkin, Adolphus Peter, M.A., PH.D., Professor of Anthropology in the University of Sydney. (President, 1940.)
1949		Ellison, Dorothy Jean, M.SC. (Hons.) *N.Z.*, Science Teacher, Abbotsleigh, Wahroonga ; p.r. 51 Tyron-road, Lindfield.
1940		Emmerton, Henry James, B.SC., 37 Wangoola-street, East Gordon.
1944		Erhart, John Charles, Chemical Engineer, c/o " Ciba " Coy., Basle, Switzerland.
1908		‡Esdaile, Edward William, 42 Hunter-street, Sydney.
1935		Evans, Silvanus Gladstone, A.I.A.A. *Lond.*, A.R.A.I.A., 6 Major-street, Coogee.
1949		Everingham, Richard, 97 Hopetoun-avenue, Vaucluse.
1950		Fallon, Joseph James, Photographer, 1 Coolong-road, Vaucluse.
1909	P 7	‡Fawsitt, Charles Edward, D.SC., PH.D., F.R.A.C.I., Emeritus Professor of Chemistry, 14A Darling Point-road, Edgecliff. (President, 1919.)
1940		Finch, Franklin Charles, B.SC., c/o Dyson Perrin's Laboratory, South Parks-road, Oxford, England.
1940		Fisher, Robert, B.SC., 3 Sackville-street, Maroubra.
1933		Fletcher, Harold Oswald, Palaeontologist, Australian Museum, College-street, Sydney.

Elected.

1949		Flinter, Basil Harold, B.Sc., Colonial Geological Survey, Federation of Malaya, Batu Gajah, Malaya.
1932		Forman, Kenn P., M.I.Refr.E., Box 1822, G.P.O., Sydney.
1943		Frederick, Robert Desider Louis, B.E., 1540 High-street, Malvern, Victoria.
1950		Freeman, Hans Charles, M.Sc., 43 Newcastle-street, Rose Bay.
1951		French, Oswald Raymond, Research Assistant, University of Sydney; p.r. 66 Nottinghill-road, Lidcombe.
1944	P 2	Friend, James Alan, M.Sc. *Syd.*, Ph.D. *Camb.*, Department of Chemistry, University of Tasmania, Box 647C, Hobart, Tas.
1945		Furst, Hellmut Friedrich, B.D.S. *Syd.*, D.M.D. *Hamburg*, Dental Surgeon, 158 Bellevue-road, Bellevue Hill.
1952		Garan, Teodar, Geological Professional Officer, 1/22nd Street, Warragamba Dam, N.S.W.
1935	P 2	Garretty, Michael Duhan, D.Sc., " Surry Lodge ", Mitcham-road, Mitcham, Victoria.
1939	P 4	Gascoigne, Robert Mortimer, Ph.D. *Liverpool*, Department of Organic Chemistry, N.S.W. University of Technology, Broadway, Sydney.
1942	P 6	Gibson, Neville Allan, M.Sc., Ph.D., A.R.I.C., 103 Bland-street, Ashfield.
1947		Gill, Naida Sugden, B.Sc., Ph.D., 45 Neville-street, Marrickville.
1947		‡Gill, Stuart Frederic, Schoolteacher, 45 Neville-street, Marrickville.
1948		Glasson, Kenneth Roderick, B.Sc., Geologist, c/o Mining and Prospecting Services, Box 847J, Melbourne.
1945		Goddard, Roy Hamilton, F.C.Aust., Royal Exchange, Bridge-street, Sydney.
1953		Golding, Henry George, A.R.C.S., B.Sc., School of Mining Engineering and Applied Geology, N.S.W. University of Technology, Broadway, Sydney.
1951		Goldstone, Charles Lillington, B.Agr.Sc. *N.Z.*, Lecturer in Sheep Husbandry, N.S.W. University of Technology, c/o East Sydney Technical College, Darlinghurst.
1947		Goldsworthy, Neil Ernest, M.B., Ch.M. *Syd.*, Ph.D., D.T.M. & H. *Camb.*, D.T.M. & H. *Eng.*, D.P.H. *Camb.*, 65 Roseville-avenue, Roseville.
1949		Gordon, William Fraser, B.Sc. *Syd.*, Industrial Chemist; p.r. 176 Avoca-street, Randwick.
1936		Goulston, Edna Maude, B.Sc., 83 Birriga-road, Bellevue Hill.
1948	P 1	Gray, Charles Alexander Menzies, B.Sc., B.E., Professor of Engineering, the University of Malaya.
1952		Gray, Noel Mackintosh, B.Sc. *W.A.*, Geologist, Research Sub-Branch, M.W.S. and D. Board, 341 Pitt-street, Sydney.
1952		Griffin, Russell John, B.Sc., Geologist, c/o Department of Mines, Sydney.
1952	P 2	Griffith, James Langford, B.A., M.Sc., Dip.Ed., Senior Lecturer in Applied Mathematics, N.S.W. University of Technology, Broadway, Sydney.
1946	P 1	Gutmann, Felix, Ph.D., F.Inst.P., M.I.R.E., N.S.W. University of Technology, Broadway, Sydney.
1948	P 8	Gyarfas, Eleonora Clara, M.Sc. *Budapest*, Ph.D. *Syd.*, Research Assistant, Chemistry Department, University of Sydney.
1947		Hall, Lennard Robert, B.Sc., Geological Survey, Department of Mines, Bridge-street, Sydney.
1934		Hall, Norman Frederick Blake, M.Sc., Chemist, 15A Wharf-road, Longueville.
1949		Hampton, Edward John William, A.S.T.C.; p.r. 1 Hunter-street, Waratah, N.S.W.
1940	P 15	Hanlon, Frederick Noel, B.Sc., Geologist, 25 Yandarlo-street, Croydon Park.
1905	P 6	‡Harker, George, D.Sc., F.R.A.C.I.; p.r. 89 Homebush-road, Strathfield.
1936		Harper, Arthur Frederick Alan, M.Sc., A.Inst.P., National Standards Laboratory, University Grounds, City-road, Chippendale.
1934		Harrington, Herbert Richard, Teacher of Physics and Electrical Engineering, Technical College, Harris-street, Ultimo.
1948	P 6	Harris, Clive Melville, B.Sc., A.S.T.C., A.R.A.C.I., Lecturer in Inorganic Chemistry, N.S.W. University of Technology, Broadway, Sydney; p.r. 12 Livingstone-road, Lidcombe.
1949		Harris, Henry Maxwell, B.Sc., B.E.
1946		Harrison, Ernest John Jasper, B.Sc., Geologist, N.S.W. Geological Survey, Department of Mines, Sydney.
1954		Hasan, Syed Manzurul, M.Sc., F.G.S., Department of Geology, University of Sydney.

Elected

1934			Hayes, William Lyall, A.S.T.C., A.R.A.C.I., Works Chemist, c/o Wm. Cooper & Nephews (Aust.) Ltd., Phillip-street, Concord; p.r. 42 Tindale-road, Artarmon.
1951			Heard, George Douglas, B.Sc., Maitland Boys' High School, East Maitland, N.S.W.
1919			‡Henriques, Frederick Lester, Billyard-avenue, Elizabeth Bay.
1952			Hewitt, John William, B.Sc., Geologist, Main Roads Department; p.r. 31 Wetherill-street, Narrabeen.
1945			Higgs, Alan Charles, Colonial Sugar Refining Co. Ltd., Pyrmont; p.r. 29 Radio-avenue, Balgowlah.
1938	P	4	Hill, Dorothy, D.Sc. Q'ld., Ph.D. Cantab., Department of Geology, University of Queensland, St. Lucia, Brisbane, Queensland.
1936			Hirst, Edward Eugene, A.M.I.E., Vice-Chairman and Joint Managing Director, British General Electric Co. Ltd.
1948	P	6	Hogarth, Julius William, B.Sc., 8 Jeanneret-avenue, Hunters Hill.
1952			Holm, Thomas John, Engineer, 524 Wilson-street, Redfern.
1951			Holmes, Robert Francis, 15 Baden-street, Coogee.
1941			Howard, Harold Theodore Clyde, M.Sc., A.R.I.C., A.R.A.C.I., A.S.T.C., Dip.Ed., Principal, Sydney Technical College, Broadway, Sydney.
1923	P	3	‡Hynes, Harold John, D.Sc.Agr., M.Sc., Assistant Director, Department of Agriculture, Box 36A, G.P.O., Sydney; p.r. " Belbooree," 704 Pacific-highway, Killara.
1943			Iredale, Thomas, D.Sc., F.R.I.C., Reader, Chemistry Department, University of Sydney; p.r. 96 Roseville-avenue, Roseville.
1942	P	1	Jaeger, John Conrad, M.A., D.Sc., Geology Department, University of Tasmania, Hobart, Tasmania.
1951			Jamieson, Helen Campbell, A.S.T.C.; p.r. 3 Hamilton-street, Coogee.
1951			Johnson, William, Geologist, c/o The Supervising Engineer, Warragamba Dam, N.S.W.
1949	P	1	Joklik, Gunther F., B.Sc., Ph.D.
1951			Jones, Roger M., Laboratory Assistant, Sydney Technical College; p.r. 69 Moore Park-road, Centennial Park.
1935	P	6	Joplin, Germaine Anne, B.A., Ph.D., D.Sc., Geophysics Department, Australian National University, Canberra, A.C.T.
1948	P	1	Jopling, Alan Victor, B.Sc., B.E.
1935			Kelly, Caroline Tennant (Mrs.), Dip.Anth.; p.r. " Avila," 17 Heydon-avenue, Warrawee.
1924	P	1	Kenny, Edward Joseph, Under Secretary of the Department of Mines, Sydney; p.r. 17 Alma-street, Ashfield.
1948			Kimble, Frank Oswald, Engineer, 16 Evelyn-avenue, Concord.
1943			Kimble, Jean Annie, B.Sc., Research Chemist, 383 Marrickville-road, Marrickville.
1920			‡Kirchner, William John, B.Sc., A.R.A.C.I., Manufacturing Chemist, c/o Messrs. Burroughs Wellcome & Co. (Australia) Ltd., Victoria-street, Waterloo; p.r. 18 Lyne-road, Cheltenham.
1948			Knight, Oscar Le Maistre, B.E. Syd., A.M.I.C.E., A.M.I.E.Aust., Engineer, 10 Mildura-street, Killara.
1948			Koch, Leo E., Dr.Phil.Hrabil Cologne, Research Lecturer, N.S.W. University of Technology, Broadway, Sydney; p.r. " Shalford," 21 Treatt's-road, Lindfield.
1939	P	3	Lambeth, Arthur James, B.Sc., " Naranje," Sweethaven-road, Wetherill Park, N.S.W.
1949			Lancaster, Kelvin John, M.A., B.Sc., B.Sc.Econ., 39 Wallaroy-road, Woollahra.
1950			Langley, Julia Mary, B.Sc., 17 Clifford-street, Gordon.
1951			Lawrence, Laurence James, B.Sc., Lecturer in Geology, N.S.W. University of Technology; p.r. 28 Church-street, Ashfield.
1936			Leach, Stephen Laurence, B.A., B.Sc., A.R.A.C.I., British Australian Lead Manufacturers Pty. Ltd., Box 21, P.O., Concord.

Elected.

1951		Minty, Edward James, B.Sc., " Roseneath," Lynch-street, Parkes, N.S.W.
1922	P 33	Morrison, Frank Richard, F.R.A.C.I., F.C.S., Deputy Director, Museum of Applied Arts and Sciences, Harris-street, Broadway, Sydney. (President, 1950-1951.)
1941		Morrissey, Mathew John, B.A., F.S.T.C., A.R.A.C.I., M.B., B.S., D.O. *Syd.*, c/o Residents' Quarters, Sydney Hospital, Macquarie-street, Sydney.
1934		Mort, Francis George Arnot, A.R.A.C.I., Chemist, 110 Green's-road, Fivedock.
1950		Mortlock, Allan John, M.Sc., Physics Department, University of Reading, England.
1948		Mosher, Kenneth George, B.Sc., Geologist, c/o Joint Coal Board, 66 King-street, Sydney.
1944		Moye, Daniel George, B.Sc., Chief Geologist, c/o Snowy Mountains Hydro-Electric Authority, Cooma, N.S.W.
1946		Mulholland, Charles St. John, B.Sc., Assistant Under-Secretary, Department of Mines, Bridge-street, Sydney.
1915		‡Murphy, Robert Kenneth, Dr.Ing.Chem., A.S.T.C., M.I.Chem.E., F.R.A.C.I., 68 Pindari-avenue, North Mosman.
1951		Murray, James Kenneth, B.Sc., 464 William-lane, Broken Hill, N.S.W.
1950		Murray, Patrick Desmond Fitzgerald, M.A., D.Sc., Professor of Zoology, University of Sydney.
1930	P 7	Naylor, George Francis King, M.A., M.Sc., Dip.Ed. *Syd.*, Ph.D. *Q'ld.*, Senior Lecturer in Psychology and Philosophy, University of Queensland, Brisbane.
1943		‡Neuhaus, John William George, 32, Bolton-street, Guildford.
1932		Newman, Ivor Vickery, M.Sc., Ph.D., F.R.M.S., F.L.S., ; p.r. 1 Stuart-street, Wahroonga.
1935		Nicol, Phyllis Mary, M.Sc., Sub-Principal, The Women's College, Newtown.
1945	P 1	Noakes, Lyndon Charles, Geologist, c/o Mineral Resources Survey, Canberra, A.C.T.
1920	P 4	‡Noble, Robert Jackson, M.Sc., B.Sc.Agr., Ph.D., Under Secretary, Department of Agriculture, Box 36A, G.P.O., Sydney ; p.r. 32A Middle Harbour-road, Lindfield. (President, 1934.)
1947		Nordon, Peter, A.S.T.C., A.R.A.C.I., Chemical Engineer, 42 Milroy-avenue, Kensington.
1940	P 25	Nyholm, Ronald Sydney, M.Sc. (*Syd.*), Ph.D., D.Sc. (*Lond.*), Professor of Inorganic Chemistry, London University College, Gower-street, London, W.C.1, England. (President, 1954.)
1951		‡O'Dea, Daryl Robert, A.S.T.C., Box 14, P.O., Broadway.
1947		Old, Adrian Noel, B.Sc.Agr., Chemist, Department of Agriculture ; p.r. 4 Springfield-avenue, Potts Point.
1921	P 13	Osborne, George Davenport, D.Sc. *Syd.*, Ph.D. *Camb.*, F.G.S., Reader in Geology in the University of Sydney. (President, 1944.)
1950		Oxenford, Reginald Augustus, B.Sc., 10 Fry-street, Grafton, N.S.W.
1951	P 3	Packham, Gordon Howard, B.Sc., 61 Earlwood-avenue, Earlwood.
1920	P 80	‡Penfold, Arthur Ramon, F.R.A.C.I., F.C.S., Director, Museum of Applied Arts and Sciences, Harris-street, Broadway, Sydney. (President, 1935.)
1948		Perry, Hubert Roy, B.Sc., 74 Woodbine-street, Bowral.
1953		Phillips, June Rosa Pitt, B.Sc., Geology Department, University of Sydney.
1938		Phillips, Marie Elizabeth, B.Sc., Ph.D. (*Manchester*), Soil Conservation Section, S.M.H.E.A., Cooma ; p.r. 4 Morella-road, Clifton Gardens.
1935		Phillips, Orwell, 55 Darling Point-road, Edgecliff.
1946		Pinwill, Norman, B.A. *Q'ld.*, The Scots College, Bellevue Hill.
1943	P 8	Plowman, Ronald Arthur, B.Sc., Ph.D. *Lond.*, A.S.T.C., A.R.A.C.I., Chemistry Department, University of Queensland, Brisbane.
1919		‡Poate, Sir Hugh Raymond Guy, M.B., Ch.M. *Syd.*, F.R.C.S. *Eng.*, L.R.C.P. *Lond.*, F.R.A.C.S., Surgeon, 225 Macquarie-street, Sydney ; p.r. 38 Victoria-road, Bellevue Hill.
1949		Poggendorff, Walter Hans George, B.Sc.Agr., Chief of the Division of Plant Industry, N.S.W. Department of Agriculture, Box 36A, G.P.O., Sydney.
1921	P 2	Powell, Charles Wilfrid Roberts, F.R.I.C., A.R.A.C.I., Company Executive, c/o Colonial Sugar Refining Co., O'Connell-street, Sydney ; p.r. " Wansfell," Kirkoswald-avenue, Mosman.

Elected.

1938			Powell, John Wallis, A.S.T.C., A.R.A.C.I., Managing Director, Foster Clark (Aust.) Ltd., 17 Thirlow-street, Redfern.
1927			Price, William Lindsay, B.E., B.SC., Teacher of Physics, Sydney Technical College ; p.r. 8 Wattle-street, Killara.
1918	P	1	‡Priestley, Henry, M.D., Ch.M., B.SC., 54 Fuller's-road, Chatswood. (President, 1942-43.)
1945			Proud, John Seymour, B.E., M. (*Aust.*), I.M.M., A.M.I.E., Mining Engineer, Finlay-road, Turramurra.
1935	P	3	‡Quodling, Florrie Mabel, B.SC., Lecturer in Geology, University of Sydney.
1953	P	3	Rade, Janis, M.SC., Geologist, Box 449, P.O., Darwin, N.T.
1922	P	8	Raggatt, Harold George, C.B.E., D.SC., Secretary, Department of National Development, Acton, Canberra, A.C.T.
1919	P	3	‡Ranclaud, Archibald Boscawen Boyd, B.SC., B.E., 57 William-street, Sydney.
1954			Rao, Veeraghanta Bhaskara, M.SC., Geology Department, University of Sydney.
1947			Ray, Reginald John, Plastics Manufacturer and Research Chemist ; p.r. " Treetops," Wyong-road, Berkeley Vale.
1931	P	1	Rayner, Jack Maxwell, B.SC., F.Inst.P., Deputy Director, Bureau of Mineral Resources, Geology and Geophysics, 485 Bourke-street, Melbourne, Vic.
1951			Rector, John, B.SC., Research Officer, Engineering Production, Metrology Division, C.S.I.R.O. ; p.r. 46 Sir Thomas Mitchell-road, Bondi Beach.
1947			Reuter, Fritz Henry, PH.D. *Berlin*, 1930, F.R.A.C.I., Associate Professor of Food Technology, N.S.W. University of Technology ; p.r. 94 Onslow-street, Rose Bay.
1950			Rickwood, Frank Kenneth, Senior Lecturer in Geology, The University of Sydney.
1947	P	1	Ritchie, Arthur Sinclair, A.S.T.C., Lecturer in Mineralogy and Geology, Newcastle University College ; p.r. 188 St. James-road, New Lambton, N.S.W.
1947			Ritchie, Bruce, B.SC. (Hons.), c/o Pyco Products Pty. Ltd., 576 Parramatta-road, Petersham ; p.r. 249 West Botany-street, Rockdale.
1939	P	19	Ritchie, Ernest, D.SC., Senior Lecturer, Chemistry Department, University of Sydney, Sydney.
1939	P	3	Robbins, Elizabeth Marie (Mrs.), M.SC., Waterloo-road, North Ryde.
1940			Robertson, Rutherford Ness, B.SC. *Syd.*, PH.D. *Cantab.*, Senior Plant Physiologist, C.S.I.R.O., Division of Food Preservation, Private Bag, P.O., Homebush ;
1949	P	8	Robertson, William Humphrey, B.SC., Astronomer, Sydney Observatory, Sydney.
1951			Robinson, David Hugh, A.S.T.C., Chemist, 21 Dudley-avenue, Roseville.
1940			Rosenbaum, Sidney, 23 Strickland-avenue, Lindfield.
1948			Rosenthal-Schneider, Ilse, PH.D., 48 Cambridge-avenue, Vaucluse.
1945			Rountree, Phyllis Margaret, D.SC. *Melb.*, Dip.Bact. *Lond.*, Royal Prince Alfred Hospital, Sydney.
1945			Sampson, Aileen (Mrs.), Sc.Dip. (A.S.T.C., 1944), 9 Knox-avenue, Epping.
1920			‡Scammell, Rupert Boswood, B.SC. *Syd.*, A.R.A.C.I., F.C.S. ; p.r. 10 Buena Vista-Avenue, Clifton Gardens.
1948	P	3	Schafer, Harry Neil Scott, B.SC., C.S.I.R.O., Coal Research Section, P.O. Box 3, Chatswood ; p.r. 18 Bartlett-street, Summer Hill.
1950			Searl, Robert Alexander, B.SC., 32 Woodlawn-avenue, Wollongong, N.S.W.
1949			See, Graeme Thomas, B.SC., A.S.T.C., Geochemist, N.S.W. University of Technology, Broadway, Sydney ; p.r. No. 1 " Kendal " Flats, 32 Ravenswood-avenue, Randwick.
1933			Selby, Edmond Jacob, Dip.Com., Sales Manager, Box 175D, G.P.O., Sydney.
1950			Sergeyeff, William Peter, Mining Geologist and Engineer.
1948			‡Sharp, Kenneth Raeburn, B.SC., c/o S.M.H.E.A., Cooma, N.S.W.
1936	P	5	Sherrard, Kathleen Margaret Maria (Mrs.), M.SC. *Melb.*, 43 Robertson-road, Centennial Park.
1945	P	3	Simmons, Lewis Michael, B.SC., PH.D. *Lond.*, F.R.A.C.I., Head of Science Department, Scots College ; p.r. The Scots College, Victoria-road, Bellevue Hill.
1948	P	2	Simonett, David Stanley, M.SC., PH.D., Assistant Professor of Geography, University of Kansas, Lawrence, Kansas, U.S.A.
1943			Simpson, John Kenneth Moore, Industrial Chemist, " Browie," Old Castle Hill-road, Castle Hill.

Elected.

1950	P	3	Sims, Kenneth Patrick, B.Sc., 13 Onyx-road, Artarmon.
1933			Slade, George Hermon, B.Sc., Director, W. Hermon Slade & Co. Pty. Ltd., Manufacturing Chemists, Mandemar-avenue, Homebush ; p.r. " Raiatea," Oyama-avenue, Manly.
1952 •			Slade, Milton John, B.Sc., 10 Elizabeth-street, Raymond Terrace, N.S.W.
1940			Smith, Eric Brian Jeffcoat, D.Phil. (Oxon.), 74 Webster-street, Nedlands, W.A.
1947	P	2	Smith-White, William Broderick, M.A. Cantab., B.Sc. Syd., Department of Mathematics, University of Sydney ; p.r. 28 Cranbrook-avenue, Cremorne.
1919			‡Southee, Ethelbert Ambrook, O.B.E., M.A., B.Sc., B.Sc.Agr., Trelawney-street, Eastwood.
1949			Stanton, Richard Limon, M.Sc., Lecturer in Geology, The University of Sydney, Sydney ; p.r. 42 Hopetoun-avenue, Mosman.
1954			Stapledon, David Hiley, B.Sc., Engineering Geologist, Section of Geology, S.M.H.E.A., Cooma, N.S.W.
1916			‡Stephen, Alfred Ernest, F.C.S., c/o Box 1158HH, G.P.O., Sydney.
1914			‡Stephens, Frederick G. N., F.R.C.S., M.B., Ch.M., 135 Macquarie-street, Sydney ; p.r. Captain Piper's-road and New South Head-road, Vaucluse.
1948	P	4	Stevens, Neville Cecil, B.Sc., Department of Geology, University of Western Australia, Nedlands, W.A.
1951	P	1	Stevens, Robert Denzil, B.Sc., F.G.S., Bureau of Mineral Resources, Canberra, A.C.T.
1900	P	1	‡Stewart, J. Douglas, B.V.Sc., F.R.C.V.S., Emeritus Professor of Veterinary Science in the University of Sydney ; p.r. Gladswood House, Gladswood Gardens, Double Bay. (President, 1927.)
1916	P	1	‡Stone, Walter George, F.S.T.C., F.R.A.C.I. ; p.r. 26 Rosslyn-street, Bellevue Hill.
1951			Stuntz, John, B.Sc., 511 Burwood-road, Belmore.
1918			‡Sullivan, Herbert Jay, Director in Charge of Research and Technical Department, c/o Lewis Berger & Sons (Australia) Ltd., Rhodes ; Box 23, P.O., Burwood ; p.r. " Stonycroft," 10 Redmyre-road, Strathfield.
1919			‡Sutherland, George Fife, A.R.C.Sc. Lond., 47 Clanwilliam-street, Chatswood.
1920			‡Sutton, Harvey, O.B.E., M.D., D.P.H. Melb., B.Sc. Oxon. ; p.r. " Lynton," 27 Kent-road, Rose Bay.
1941	P	2	Swanson, Thomas Baikie, M.Sc. Adel., c/o Technical Service Department, Icianz, Box 1911, G.P.O., Melbourne, Victoria.
1948			Swinbourne, Ellice Simmons, Organic Chemist, A.S.T.C., A.R.A.C.I., 1 Raglan-street, Manly.
1954			Taylor, Griffith, D.Sc., B.E., B.A., Emeritus Professor of Geography, University of Sydney ; p.r. 28 Alan-avenue, Seaforth.
1915	P	3	‡Taylor, Brigadier Harold B., M.C., D.Sc., F.R.I.C., F.R.A.C.I., 12 Wood-street, Manly.
1944			Thomas, Andrew David, Squadron Leader, R.A.A.F., M.Sc., A.Inst.P., 26 Darebin-street, Heidelberg, N.22, Victoria.
1952			Thomas, Penrhyn Francis, A.S.T.C., Optometrist, Suite 22, 3rd Floor, 49 Market-street, Sydney.
1946	P	2	Thompson, Nora (Mrs.), B.Sc. Syd., c/o Mines Department, Wau, T.N.G.
1954			Tompkins, Denis Keith, B.Sc., 24 The Crescent, Lane Cove.
1940			Tow, Aubrey James, M.Sc., M.B., B.S., c/o Community Hospital, Canberra, A.C.T.
1949			Trebeck, Prosper Charles Brian, J.P., F.A.S.A., F.Com.A. (Eng.), F.C.I. (Aust.), A.C.I.S., P.O. Box 23, Deniliquin, 6.S, N.S.W.
1951			Tugby, Elise Evelyn (Mrs.), B.Sc. ; p.r. c/o Department of Anthropological Sociology, Australian National University, Box 4, G.P.O., Canberra, A.C.T.
1952			Ungar, Andrew, Dipl.Ing., Dr.Inq., 6 Ashley Grove, Gordon.
1949	P	1	Vallance, Thomas George, B.Sc., Ph.D., F.G.S., Geology Department, University of Sydney.
1953			Veevers, John James, B.Sc., c/o Geology Department, Imperial College, London, England.
1921			Vicars, Robert, Marrickville Woollen Mills, Marrickville.
1935			Vickery, Joyce Winifred, M.Sc., F.L.S., Botanic Gardens, Sydney ; p.r. 17 The Promenade, Cheltenham.

Elected.

1933	P 6	Voisey, Alan Heywood, D.Sc., Lecturer in Geology and Geography, New England University, Armidale.
1903	P 10	‡Vonwiller, Oscar U., B.Sc., F.Inst.P., Emeritus Professor of Physics in the University of Sydney; p.r. " Avila," 17 Heydon-avenue, Warrawee. (President, 1930.)
1948		Walker, Donald Francis, Surveyor, 13 Beauchamp-avenue, Chatswood.
1919	P 2	‡Walkom, Arthur Bache, D.Sc., 45 Nelson-road, Killara. (Member from 1910-1913. President, 1943-44.)
1948		Ward, Mrs. Judith, B.Sc., Wayatinah, Tasmania.
1913	P 5	‡Wardlaw, Hy. Sloane Halcro, D.Sc. *Syd.*, F.R.A.C.I., c/o Kanematsu Institute, Sydney Hospital, Macquarie Street, Sydney. (President, 1939.)
1919	P 1	‡Waterhouse, Lionel Lawry, B.E. *Syd.*, " Rarotonga," 42 Archer-street, Chatswood.
1919	P 7	‡Waterhouse, Walter L., C.M.G., M.C., D.Sc.Agr., D.I.C., F.L.S.; p.r. " Hazelmere," Chelmsford Avenue, Lindfield. (President, 1937.)
1944		Watkins, William Hamilton, B.Sc., Industrial Chemist, c/o Cablemakers (Aust.) Pty. Ltd., Illawarra Road, Liverpool, N.S.W.
1911	P 1	‡Watt, Robert Dickie, M.A., B.Sc., Emeritus Professor of Agriculture, Sydney University, " Garron Tower," 5 Gladswood Gardens, Double Bay. (President, 1925.)
1921		‡Watts, Arthur Spencer, " Araboonoo," Glebe-street, Randwick.
1951		Weatherhead, Albert Victor, F.R.M.S., F.R.P.S.
1954		West, Norman William, B.Sc., Chemist, Department of Main Roads, Sydney; p.r. 11 McMillan-road, Artarmon.
1949		Westheimer, Gerald, B.Sc., Ph.D., F.S.T.C., F.A.A.O., Optometrist.
1951		Whitley, Alice, B.Sc., Teacher, 39 Belmore-street, Burwood.
1951	P 3	Whitworth, Horace Francis, M.Sc., Mining Museum, Sydney.
1949		Williams, Benjamin, A.S.T.C., 14 Francis-street, Artarmon.
1949		Williamson, William Harold, Hughes-avenue, Ermington.
1954		Wood, Clive Charles, B.Sc., B.E., Engineering Geologist, S.M.H.E.A., Cooma, N.S.W.
1936	P 12	Wood, Harley Weston, M.Sc., A.Inst.P., F.R.A.S., Government Astronomer, Sydney Observatory, Sydney. (President, 1949.)
1906	P 12	‡Woolnough, Walter George, D.Sc., F.G.S., 28 Calbina-road, Northbridge. (President, 1926.)
1946		Wyndham, Norman Richard, M.D., M.S. *Syd.*, F.R.C.S. *Eng.*, F.R.A.C.S., Surgeon, 225 Macquarie-street, Sydney.
1952		Wynn, Desmond Watkin, B.Sc., Geologist, c/o Department of Mines, Sydney.
1950		Zehnder, John Oscar, B.Sc., Geologist, c/o Australasian Petroleum Coy., Port Moresby, Papua.

HONORARY MEMBERS.

Limited to Twenty.

Elected.

1949   Burnet, Sir Frank Macfarlane, M.D., Ph.D., F.R.S., Director of the Walter and Eliza Hall Research Institute, Melbourne.

1951   Fairley, Sir Neil Hamilton, C.B.E., M.D., D.SC., F.R.S., 73 Harley-street, London, W.1.

1952   Firth, Raymond William, M.A., Ph.D., Professor of Anthropology, University of London, London School of Economics, Houghton-street, Aldwych, W.C.2, England.

1949   Florey, Sir Howard, M.B., B.S., B.SC., M.A., Ph.D., F.R.S., Professor of Pathology, Oxford University, England.

1946   Jones, Sir Harold Spencer, M.A., D.SC., F.R.S., Astronomer Royal, Royal Observatory, Greenwich, London, S.E.10.

1912   Martin, Sir Charles J., C.M.G., D.SC., F.R.S., Roebuck House, Old Chesterton, Cambridge, England.

1953   O'Connell, Rev. Daniel J. K., S.J., D.SC., D.Ph., F.R.A.S., Director, The Vatican Observatory, Rome, Italy.

1948   Oliphant, Marcus L., B.SC., Ph.D., F.R.S., Professor of Physics, The Australian National University, Canberra, A.C.T.

1948   Robinson, Sir Robert, M.A., D.SC., F.C.S., F.I.C., F.R.S., Professor of Chemistry, Oxford University, England.

OBITUARY, 1954-55.

1903   Horatio Scott Carslaw.

1914   James P. Hill.

1938   Gordon Kingsley Hughes.

1927   Frederick D. McMaster.

1923   Richmond Douglas Toppin.

1916   George Wright.

1947   Frederic Wood Jones.

THE REV. W. B. CLARKE MEMORIAL FUND.

The Rev. W. B. Clarke Memorial Fund was inaugurated at a meeting of the Royal Society of N.S.W. in August, 1878, soon after the death of Mr. Clarke, who for nearly forty years rendered distinguished service to his adopted country, Australia, and to science in general. It was resolved to give an opportunity to the general public to express their appreciation of the character and services of the Rev. W. B. Clarke " as a learned colonist, a faithful minister of religion, and an eminent scientific man." It was proposed that the memorial should take the form of lectures on Geology (to be known as the Clarke Memorial Lectures), which were to be free to the public, and of a medal to be given from time to time for distinguished work in the Natural Sciences done in or on the Australian Commonwealth and its territories ; the person to whom the award is made may be resident in the Australian Commonwealth or its territories, or elsewhere.

The Clarke Memorial Medal was established first, and later, as funds permitted, the Clarke Memorial Lectures have been given at intervals.

CLARKE MEMORIAL LECTURES.

Delivered.

1906. "The Volcanoes of Victoria," and "The Origin of Dolomite" (two lectures). By Professor E. W. Skeats, D.Sc., F.G.S.

1907. "Geography of Australia in the Permo-Carboniferous Period" (two lectures). By Professor T. W. E. David, B.A., F.R.S.
"The Geological Relations of Oceania." By W. G. Woolnough, D.Sc.
"Problems of the Artesian Water Supply of Australia." By E. F. Pittman, A.R.S.M.
"The Permo-Carboniferous Flora and Fauna and their Relations." By W. S. Dun.

1918. "Brain Growth, Education, and Social Inefficiency." By Professor R. J. A. Berry, M.D., F.R.S.E.

1919. "Geology at the Western Front," By Professor T. W. E. David, C.M.G., D.S.O., F.R.S.

1936. "The Aeroplane in the Service of Geology." By W. G. Woolnough, D.Sc. (THIS JOURN., 1936, 70, 39.)

1937. "Some Problems of the Great Barrier Reef." By Professor H. C. Richards, D.Sc. (THIS JOURN., 1937, 71, 68.)

1938. "The Simpson Desert and its Borders." By C. T. Madigan, M.A., B.Sc., B.E., D.Sc. (Oxon.). (THIS JOURN., 1938, 71, 503.)

1939. "Pioneers of British Geology." By Sir John S. Flett, K.B.E., D.Sc., LL.D., F.R.S. (THIS JOURN., 1939, 73, 41.)

1940. "The Geologist and Sub-surface Water." By E. J. Kenny, M.Aust.I.M.M. (THIS JOURN., 1940, 74, 283.)

1941. "The Climate of Australia in Past Ages." By C. A. Sussmilch, F.G.S. (THIS JOURN., 1941, 75, 47.)

1942. "The Heroic Period of Geological Work in Australia." By E. C. Andrews, B.Sc.

1943. "Australia's Mineral Industry in the Present War." By H. G. Raggatt, D.Sc.

1944. "An Australian Geologist Looks at the Pacific." By W. H. Bryan, M.C., D.Sc.

1945. "Some Aspects of the Tectonics of Australia." By Professor E. S. Hills, D.Sc., Ph.D.

1946. "The Pulse of the Pacific." By Professor L. A. Cotton, M.A., D.Sc.

1947. "The Teachers of Geology in Australian Universities." By Professor H. S. Summers, D.Sc.

1948. "The Sedimentary Succession of the Bibliando Dome : Record of a Prolonged Proterozoic Ice Age." By Sir Douglas Mawson, O.B.E., F.R.S., D.Sc., B.E.

1949. "Metallogenetic Epochs and Ore Regions in Australia." By W. R. Browne, D.Sc.

1950. "The Cambrian Period in Australia." By F. W. Whitehouse, Ph.D., D.Sc.

1951. "The Ore Minerals and their Textures." By A. B. Edwards, D.Sc., Ph.D., D.I.C.

1953. "Some Problems of Tertiary Geology in Southern Australia." By M. F. Glaessner, Ph.D. (Vienna), D.Sc. (Melb.).

AWARDS OF THE CLARKE MEDAL.

Established in memory of

The Revd. WILLIAM BRANWHITE CLARKE, M.A., F.R.S., F.G.S., etc.

Vice-President from 1866 to 1878.

The prefix *, indicates the decease of the recipient.

Awarded.

1878 *Professor Sir Richard Owen, K.C.B., F.R.S.
1879 *George Bentham, C.M.G., F.R.S.
1880 *Professor Thos. Huxley, F.R.S.
1881 *Professor F. M'Coy, F.R.S., F.G.S.
1882 *Professor James Dwight Dana, LL.D.
1883 *Baron Ferdinand von Mueller, K.C.M.G., M.D., Ph.D., F.R.S., F.L.S.
1884 *Alfred R. C. Selwyn, LL.D., F.R.S., F.G.S.
1885 *Sir Joseph Dalton Hooker, O.M., G.C.S.I., C.B., M.D., D.C.L., LL.D., F.R.S.
1886 *Professor L. G. De Koninck, M.D.
1887 *Sir James Hector, K.C.M.G., M.D., F.R.S.
1888 *Rev. Julian E. Tenison-Woods, F.G.S., F.L.S.
1889 *Robert Lewis John Ellery, F.R.S., F.R.A.S.
1890 *George Bennett, M.D., F.R.C.S. *Eng.*, F.L.S., F.Z.S.
1891 *Captain Frederick Wollaston Hutton, F.R.S., F.G.S.
1892 *Sir William Turner Thiselton Dyer, K.C.M.G., C.I.E., M.A., LL.D., SC.D., F.R.S., F.L.S.
1893 *Professor Ralph Tate, F.L.S., F.G.S.
1895 *Robert Logan Jack, LL.D., F.G.S., F.R.G.S.
1895 *Robert Etheridge, Jnr.
1896 *The Hon. Augustus Charles Gregory, C.M.G., F.R.G.S.
1900 *Sir John Murray, K.C.B., LL.D., SC.D., F.R.S.
1901 *Edward John Eyre.
1902 *F. Manson Bailey, C.M.G., F.L.S.
1903 *Alfred William Howitt, D.SC., F.G.S.
1907 *Professor Walter Howchin, F.G.S., University of Adelaide.
1909 *Dr. Walter E. Roth, B.A.
1912 *W. H. Twelvetrees, F.G.S.
1914 *Sir A. Smith Woodward, LL.D., F.R.S., Keeper of Geology, British Museum (Natural
         History), London.
1915 *Professor W. A. Haswell, M.A., D.SC., F.R.S.
1917 *Professor Sir Edgeworth David, K.B.E., C.M.G., D.S.O., M.A., SC.D., D.SC., F.R.S., F.G.S.
1918 *Leonard Rodway, C.M.G., Honorary Government Botanist, Hobart, Tasmania.
1920 *Joseph Edmund Carne, F.G.S.
1921 *Joseph James Fletcher, M.A., B.SC.
1922 *Richard Thomas Baker, The Crescent, Cheltenham.
1923 *Sir W. Baldwin Spencer, K.C.M.G., M.A., D.SC., F.R.S.
1924 *Joseph Henry Maiden, I.S.O., F.R.S., F.L.S., J.P.
1925 *Charles Hedley, F.L.S.
1927 *Andrew Gibb Maitland, F.G.S., " Bon Accord," 28 Melville Terrace, South Perth, W.A.
1928 *Ernest C. Andrews, B.A., F.G.S., 32 Benelong Crescent, Bellevue Hill.
1929 *Professor Ernest Willington Skeats, D.SC., A.R.C.S., F.G.S., University of Melbourne,
         Carlton, Victoria.
1930 L. Keith Ward, B.A., B.E., D.SC., Government Geologist, Geological Survey Office, Adelaide.
1931 *Robin John Tillyard, M.A., D.SC., SC.D., F.R.S., F.L.S., F.E.S., Canberra, F.C.T.
1932 *Frederick Chapman, A.L.S., F.R.S.N.Z., F.G.S., Melbourne.
1933 Walter George Woolnough, D.SC., F.G.S., Department of the Interior, Canberra, F.C.T.
1934 *Edward Sydney Simpson, D.SC., B.E., F.A.C.I., Carlingford, Mill Point, South Perth, W.A.
1935 *George William Card, A.R.S.M., 16 Ramsay-street, Collaroy, N.S.W.
1936 Sir Douglas Mawson, Kt., O.B.E., F.R.S., D.SC., B.E., University of Adelaide.
1937 J. T. Jutson, B.SC., LL.B., 9 Ivanhoe-parade, Ivanhoe, Victoria.
1938 *Professor H. C. Richards, D.SC., The University of Queensland, Brisbane.
1939 *C. A. Sussmilch, F.G.S., F.S.T.C., 11 Appian Way, Burwood, N.S.W.
1941 *Professor Frederic Wood Jones, M.B., B.S., D.SC., F.R.S., Anatomy Department, University
         of Manchester, England.
1942 William Rowan Browne, D.SC., Reader in Geology, The University of Sydney, N.S.W.
1943 Walter Lawry Waterhouse, M.C., D.SC.Agric., D.I.C., F.L.S., Reader in Agriculture,
         University of Sydney.
1944 *Professor Wilfred Eade Agar, O.B.E., M.A., D.SC., F.R.S., University of Melbourne, Carlton,
         Victoria.

1945   Professor William Noel Benson. B.A., D.SC., F.G.S., F.R.G.S., F.R.S.N.Z., F.G.S.Am., University of Otago, Dunedin, N.Z.
1946   Black, J. M., A.L.S. (*honoris causa*), Adelaide, S.A.
1947   *Hubert Lyman Clark, A.B. D.SC., PH.D., Hancock Foundation, U.S.C., Los Angeles, California.
1948   Walkom, Arthur Bache, D.SC., Director, Australian Museum, Sydney.
1949   Rupp, Rev. H. Montague, 24 Kameruka-road, Northbridge.
1950   Mackerras, Ian Murray, B.SC., M.B., Ch.M., The Queensland Institute of Medical Research, Brisbane.
1951   Stillwell, Frank Leslie, D.SC., C.S.I.R.O., Melbourne.
1952   Wood, Joseph G., PH.D. *Cantab.*, D.SC. *Adel.*, Professor of Botany, University of Adelaide, South Australia.
1953   Nicholson, A. J., D.SC., C.S.I.R.O., Division of Entomology, Canberra.
1954   Robertson, Rutherford Ness, B.SC. (*Syd.*), PH.D. (*Cantab.*), C.S.I.R.O. Plant Physiology Unit, Sydney.

AWARDS OF THE JAMES COOK MEDAL.

Bronze Medal.

Awarded annually for outstanding contributions to science and human welfare in and for the Southern Hemisphere.

1947   Smuts, Field-Marshal The Rt. Hon. J. C., P.C., C.H., K.C., D.T.D., LL.D., F.R.S., Chancellor, University of Capetown, South Africa.
1948   Houssay, Bernado A., Professor of Physiology, Instituto de Biologia y Medicina Experimental, Buenos Aires, Argentina.
1949   No award made.
1950   Fairley, Sir Neil Hamilton, C.B.E., M.D., D.SC., F.R.S., 73 Harley-street, London, W.1.
1951   Gregg, Norman McAlister, M.B., B.S., 193 Macquarie-street, Sydney.
1952   Waterhouse, Walter L., M.C., D.Sc.Agr., D.I.C., F.L.S., " Hazelmere," Chelmsford-avenue, Lindfield.
1953   Rivett, Sir David, K.C.M.G., M.A., D.SC., F.R.S., 11 Eton Square, 474 St. Kilda-road, Melbourne, S.C.2, Victoria.
1954   Burnet, Sir Frank Macfarlane, M.D., PH.D., F.R.S., Director, Walter and Eliza Hall Research Institute, Melbourne, Victoria.

AWARDS OF THE EDGEWORTH DAVID MEDAL.

Bronze Medal.

Awarded annually for Australian research workers under the age of thirty-five years, for work done mainly in Australia or its territories or contributing to the advancement of Australian Science.

1948   Giovanelli, R. G., M.SC., Division of Physics, National Standards Laboratory, Sydney. Ritchie, Ernest, M.SC., University of Sydney, Sydney. } Joint Award.
1949   Kiely, Temple B., D.Sc.Agr., Caroline-street, East Gosford.
1950   Berndt, Ronald M., B.A., Dip.Anthr., University of Sydney. Berndt, Catherine H., M.A., Dip.Anthr., University of Sydney. } Joint Award.
1951   Bolton, John G., B.A., C.S.I.R.O., Division of Radiophysics, Sydney.
1952   Wardrop, Alan B., PH.D., C.S.I.R.O., Division of Forest Products, South Melbourne.
1953   No award made.
1954   Barnes, Eric Stephen, PH.D. (*Camb.*), University of Sydney, Sydney.

AWARDS OF THE SOCIETY'S MEDAL AND MONEY PRIZE.

Money Prize of £25.

1882   John Fraser, B.A., West Maitland, for paper entitled " The Aborigines of New South Wales."
1882   Andrew Ross, M.D., Molong, for paper entitled " Influence of the Australian climate and pastures upon the growth of wool."

The Society's Bronze Medal.

1884   W. E. Abbott, Wingen, for paper entitled " Water supply in the Interior of New South Wales."
1886   S. H. Cox, F.G.S., F.C.S., Sydney, for paper entitled " The Tin deposits of New South Wales."
1887   Jonathan Seaver, F.G.S., Sydney, for paper entitled " Origin and mode of occurrence of gold-bearing veins and of the associated Minerals."
1888   Rev. J. E. Tenison-Woods, F.G.S., F.L.S., Sydney, for paper entitled " The Anatomy and Life-history of Mollusca peculiar to Australia."
1889   Thomas Whitelegge, F.R.M.S., Sydney, for paper entitled " List of the Marine and Fresh-water Invertebrate Fauna of Port Jackson and Neighbourhood."
1889   Rev. John Mathew, M.A., Coburg, Victoria, for paper entitled " The Australian Aborigines."
1891   Rev. J. Milne Curran, F.G.S., Sydney, for paper entitled " The Microscopic Structure of Australian Rocks."
1892   Alexander G. Hamilton, Public School, Mount Kembla, for paper entitled " The effect which settlement in Australia has produced upon Indigenous Vegetation."
1894   J. V. De Coque, Sydney, for paper entitled the " Timbers of New South Wales."
1894   R. H. Mathews, L.S., Parramatta, for paper entitled " The Aboriginal Rock Carvings and Paintings in New South Wales."
1895   C. J. Martin, D.Sc., M.B., F.R.S., Sydney, for paper entitled " The physiological action of the venom of the Australian black snake (*Pseudechis porphyriacus*)."
1896   Rev. J. Milne Curran, Sydney, for paper entitled " The occurrence of Precious Stones in New South Wales, with a description of the Deposits in which they are found."
1943   Edwin Cheel, Sydney, in recognition of his contributions in the field of botanical research and to the advancement of science in general.
1948   Waterhouse, Walter L., M.S., D.Sc.Agr., D.I.C., F.L.S., Sydney, in recognition of his valuable contributions in the field of agricultural research.
1949   Elkin, Adolphus P., M.A., Ph.D., Sydney, in recognition of his valuable contributions in the field of Anthropological Science.
1950   Vonwiller, Oscar U., B.Sc., F.Inst.P., Sydney, in recognition of his valuable contributions in the field of Physical Science.
1951   Penfold, Arthur Ramon, F.R.A.C.I., F.C.S., Sydney, in recognition of his valuable researches in the chemistry of Essential Oils.
1952   No award made.
1953   Walkom Arthur Bache, D.Sc., Sydney, in recognition of his valuable contributions to Palæobotany.
1954   Mellor, David Paver, D.Sc., F.R.A.C.I., Sydney, in recognition of his valuable contributions in the field of Chemistry.

AWARDS OF THE WALTER BURFITT PRIZE.

Bronze Medal and Money Prize of £75.

Established as the result of a generous gift to the Society by Dr. W. F. BURFITT, B.A., M.B., Ch.M., B.Sc., of Sydney, which was augmented later by a gift from Mrs. W. F. BURFITT. Awarded at intervals of three years to the worker in pure and applied science, resident in Australia or New Zealand, whose papers and other contributions published during the past six years are deemed of the highest scientific merit, account being taken only of investigations described for the first time, and carried out by the author mainly in these Dominions.

Awarded.
1929   Norman Dawson Royle, M.D., Ch.M., 185 Macquarie Street, Sydney.
1932   Charles Halliby Kellaway, M.C., M.D., M.S., F.R.C.P., The Walter and Eliza Hall Institute of Research in Pathology and Medicine, Melbourne.
1935   Victor Albert Bailey, M.A., D.Phil., Associate-Professor of Physics, University of Sydney.
1938   Frank Macfarlane Burnet, M.D. (*Melb.*), Ph.D. (*Lond.*), The Walter and Eliza Hall Institute of Research in Pathology and Medicine, Melbourne.
1941   Frederick William Whitehouse, D.Sc., Ph.D., University of Queensland, Brisbane.
1944   Hereward Leighton Kesteven, D.Sc., M.D., c/o Allied Works Council, Melbourne.
1947   John Conrad Jaeger, M.A., D.Sc., University of Tasmania, Hobart.
1950   Martyn, David F., D.Sc (*Lond.*), F.R.S., Radio Research Board, c/o Commonwealth Observatory, Mount Stromlo, Canberra, A.C.T.
1953   Bullen, Keith E., M.A., Ph.D., F.R.S., Professor of Applied Mathematics, the University of Sydney.

B

AWARDS OF LIVERSIDGE RESEARCH LECTURESHIP.

This Lectureship was established in accordance with the terms of a bequest to the Society by the late Professor Archibald Liversidge. Awarded at intervals of two years, for the purpose of encouragement of research in Chemistry. (THIS JOURNAL, Vol. LXII, pp. x-xiii, 1928.)

Awarded.

1931   Harry Hey, c/o The Electrolytic Zinc Company of Australasia, Ltd., Collins Street, Melbourne.

1933   W. J. Young, D.Sc., M.Cc., University of Melbourne.

1940   G. J. Burrows, B.Sc., University of Sydney.

1942   J. S. Anderson, B.Sc., Ph.D. (*Lond.*), A.R.C.S., D.I.C., University of Melbourne.

1944   F. P. Bowden, Ph.D., Sc.D., University of Cambridge, Cambridge, England.

1946   Briggs, L. H., D.Phil (*Oxon.*), D.Sc. (*N.Z.*), F.N.Z.I.C., F.R.S.N.Z., Auckland University College, Auckland, N.Z.

1948   Ian Lauder, M.Sc., Ph.D., University of Queensland, Brisbane.

1950   Hedley R. Marston, F.R.S., C.S.I.R.O., Adelaide.

1952   A. L. G. Rees, D.Sc., C.S.I.R.O., Division of Industrial Chemistry, Melbourne.

1954   M. R. Lemberg, D.Phil., F.R.S., Institute of Medical Research, Royal North Shore Hospital, St. Leonards, N.S.W.

Royal Society of New South Wales

REPORT OF THE COUNCIL FOR THE YEAR ENDING 31st MARCH, 1955.

PRESENTED AT THE ANNUAL AND GENERAL MONTHLY MEETING OF THE SOCIETY,
6TH APRIL, 1955, IN ACCORDANCE WITH RULE XXVI.

The membership of the Society at the end of the period under review stood at 354.   Ten new members were elected during the year, and the following members were lost by resignation : Samuel R. Brown, William Dudgeon, Colin B. Kirkpatrick, Stanley E. Livingstone, Raymond N. Lyons, Alwyn W. Prescott, Reginald H. Scott, Eric C. Tommerup and Ivan Stewart Turner.

The name of James Roy Backhouse was erased from the List of Members.

Seven members have been lost to the Society by death since 1st April, 1954 :

> Horatio S. Carslaw (elected 1903).
> Gordon K. Hughes (elected 1938).
> Frederick D. McMaster (elected 1927)
> Richmond D. Toppin (elected 1923).
> George Wright (elected 1917).

and Honorary Members :

> James P. Hill (elected 1914).
> Frederic Wood Jones (elected 1947).

During the year nine General Monthly Meetings were held, the average attendance being 54.

Addresses given during the year were as follows :

5th May :
> " Education in India ", by Mr. Muni Lal, First Secretary of Information to the High Commissioner of India.

2nd June :
> " Virus Vaccines—with Special Reference to Poliomyelitis ", by Dr. N. F. Stanley, Institute of Epidemiology and Preventive Medicine at the Prince Henry Hospital, Little Bay.

7th July :
Two papers (previously read by title only) were expanded and presented as addresses.   These were :
> " Organ Transformation Induced by Œstrogen in an Adolescent Marsupial (*Trichosurus vulpecula*) with Additional Remarks on ' Change of Sex ' ", by Dr. A. Bolliger.
> " The T-Phase, a Seismological Problem ", by Rev. T. N. Burke-Gaffney, S.J.

4th August :
> " Man's Place in Evolution ", by Dr. N. W. G. Macintosh.
> " The Implications of Genetics for Darwinism ", by Dr. J. M. Rendel.

The meeting devoted to the Commemoration of Great Scientists was held on 1st September, and the following addresses were given :
> " Sir Lazarus Fletcher " (Mineralogist), by Dr. G. D. Osborne.
> " Georg Simon Ohm, 1787–1854 " (Physicist), by Dr. R. C. L. Bosworth.
> " Paul Ehrlich " (Organic Chemist and Immunologist), by Dr. Phyllis M. Rountree.

Symposium.—In place of the General Monthly Meeting for October, a symposium on " Oil, Australia and the Future " was held, at which the speakers were :

Dr. H. G. Raggatt : " The Search for Oil in Australia."
Professor T. G. Hunter : " Oil Products and Their Utilization."
Dr. R. F. Cane : " Petroleum Chemicals."
Professor C. Renwick : " The Economic Effects of an Oil Industry on the Australian Economy."

BB

His Excellency the Governor of New South Wales was present at the symposium, which commenced at 5 p.m. and concluded at 9 p.m. This meeting, which was open to the public, was most successful, the attendance being 140. Printed copies of the addresses given at the symposium will be distributed to members.

Film.—The meeting held 3rd November was devoted to the screening of the following film : " Ninety Degrees South "

made by H. Ponting, F.R.P.S., and described by him as " an account of experiences with Captain Scott's South Pole Expedition and of the nature life of the Antarctic " and had been made available to the Society through the courtesy of the New South Wales Film Council. Professor Griffith Taylor, a member of the expedition and a member of this Society, gave the introductory address.

Discussions.—In place of the Popular Science Lectures, discussions on topical subjects were held :

20th May :

" Would Space Travel be Worthwhile ? " The speakers leading the discussion were Professor F. S. Cotton, Dr. D. F. Martyn and Professor A. H. Willis.

16th September :

" Was Myxomatosis Wise ? " The speakers leading the discussion were Dr. Phyllis M. Rountree and Mr. Grahame Edgar.

1st December :

The evening of the General Monthly Meeting held 1st December was devoted to a discussion on " Fuel and Power in New South Wales ". The principal speakers were : Mr. Charles M. Sapsford—" The Potentialities for Utilization of Solar Energy " ; Dr. R. N. Robertson—" Solar Energy and Photosynthesis " ; Mr. H. E. Dann—" The Future of Water Power in New South Wales " ; Mr. H. R. Brown—" Power Resources in Coal—The Future Outlook for New South Wales Supplies ".

Papers.—Seventeen papers were accepted for reading and publication by the Society. This was the same number accepted as for the previous year, and it is anticipated that the Journal will be approximately the same size as that of 1953.

Abstract of Proceedings.—Members will have noticed that the " Abstract of Proceedings " is now being included on the monthly notice papers. These monthly abstracts will be published in the Journal, commencing with Volume 88.

Annual Social Function.—A Sherry Party was held on 31st March, and was attended by 77 members and their friends. His Excellency the Governor of New South Wales honoured the Society by attending the function.

The Section of Geology had as Chairman Dr. J. A. Dulhunty, and Mr. R. D. Stevens was Hon. Secretary of the Section until 19th November, at which meeting Mr. H. G. Golding was elected Hon. Secretary for the remainder of the session. Nine meetings were held during the year, the average attendance being 22 members and visitors. The meetings included addresses, notes and exhibits.

The Council of the Society held 12 ordinary meetings and one special meeting. The attendance of members of Council was as follows : Prof. R. S. Nyholm, 11 ; Dr. R. C. L. Bosworth, 11 ; Dr. Ida A. Browne, 11 ; Dr. C. J. Magee, 10 (on leave for two meetings) ; Dr. Phyllis M. Rountree, 10 ; Mr. J. L. Griffith, 12 ; Mr. F. N. Hanlon, 8 ; Mr. H. A. J. Donegan, 12 ; Prof. J. P. Baxter, 1 ; Rev. T. N. Burke-Gaffney, 13 ; Prof. G. Bosson, 3 ; Prof. D. P. Craig, 7 ; Dr. N. A. Gibson, 10 ; Dr. M. R. Lemberg, 7 ; Mr. F. D. McCarthy, 13 ; Prof. P. R. McMahon, 5 ; Dr. G. D. Osborne, 10 ; Mr. J. S. Proud, 9.

The President, Associate Professor R. S. Nyholm, left for overseas on 26th February to occupy a Chair of Chemistry at University College, London. The senior Vice-President, Dr. Ida A. Browne, was appointed Acting President from that date to the end of the current session.

On Science House Management Committee, the Society was represented by Mr. H. A. J. Donegan and Dr. R. C. L. Bosworth ; substitute representatives were Mr. F. R. Morrison and Mr. J. S. Proud.

Science House Extension Committee.—After some consideration by the owner bodies, it was agreed that the proposed extensions to Science House could not be carried out in the foreseeable future, and it was decided to disband the Science House Extensions Committee.

Election of Honorary Secretary.—Owing to illness, Professor Bosson resigned from office as Hon. Secretary and, at the Council meeting held on 29th September, Mr. J. L. Griffith was elected to this position on the Council.

Alteration to the Rules.—At the General Monthly Meeting held on 7th April, the following motion was adopted :

" That from Rule VIII the following words be deleted : ' Candidates must be at least twenty-one years of age '."

Commemoration of the Landing of Captain James Cook.—The President attended this commemoration at Kurnell on 1st May and, for the first time, a wreath was placed on the Banks Memorial as from the Royal Society of New South Wales, " in commemoration of Sir Joseph Banks, a member of James Cook's Expedition and First Scientist to land on these shores ".

At the meeting of the Board of Visitors of the Sydney Observatory held on 16th March, Dr. Ida A. Browne represented the Society.

Professor K. E. Bullen, F.R.S., was elected to the presidency of the International Seismological Union.

The Clarke Medal for 1955 was awarded to Dr. R. N. Robertson for distinguished work in plant physiology, particularly on salt respiration and its relation to respiration, and on the growth and metabolism of fruits.

The Society's Medal for 1954 was awarded to Dr. D. P. Mellor in recognition of his services to the Society and valuable contributions to the field of chemistry.

The James Cook Medal for 1954 was awarded to Sir Frank Macfarlane Burnet, F.R.S., in recognition of the outstanding contributions made by him in the field of virus research.

The Edgeworth David Medal for 1954 was awarded to Dr. E. S. Barnes for outstanding contributions made in the field of mathematical science, particularly his work on the geometry of numbers.

The Liversidge Research Lecture for 1954 was delivered by Dr. M. R. Lemberg, F.R.S., on 15th July. The title of the lecture was " Chemical Structure and Biological Function of the Pyrrole Pigments and Enzymes ".

Decoration and Lighting of Office and Committee Room.—The ceilings and walls of the office and committee room have been decorated and new lighting installed, at a cost of £120 7s. 6d. This cost covers also the new lighting installed in the library.

The financial position of the Society, as disclosed by the audit, shows a deficit of £331 4s., an increase of £146 11s. 4d. on the deficit of the previous year.

The Society's share of the profits from Science House for the year was £410 15s. In June, the Science House Management Committee, on behalf of the three owner bodies, approached the Fair Rents Court to obtain some relief from the effect of increased cost of management. The court's decision, while increasing rates generally, considerably increased the rent payable by this Society compared with other owner bodies, or even with non-owner tenants. The rentals to be charged owner bodies is still under consideration by the Management Committee.

Contingent Liability.—During the year the Society had to meet a liability of £368 10s., being one-third of the refund paid by the owner bodies to the Australian National Research Council, whose lease of space in Science House was terminated in November.

The Society has again received a grant from the Government of New South Wales. An increase of £100 was made to the grant, bringing the amount commencing July, 1954, to £500 for the year 1954–55. The Government's continued interest in the work of the Society is much appreciated.

The Library.—The Library Committee met twice during the year ended 28th February. The committee consisted of Professor Nyholm, Mr. Hanlon, Mr. Griffith, Dr. Bosworth, Dr. Magee, Dr. Rountree, Dr. Mellor and Mr. Wood. The assistant librarian, Mrs. B. Sommerville, attended the meetings by invitation.

The amount of £75 0s. 3d. was expended on the purchase of periodicals. Commencing November, 1954, all publications of the Royal Society, London, are being obtained by subscription, the Royal Society having cancelled its exchange with this Society because of high publication costs.

The amount of £171 17s. 6d. has been spent on binding journals in the library. A special grant of £60 was voted by Council in addition to the usual sum of £80 per annum allocated for binding. A credit balance of £33 9s. from the previous allocation has now been used.

Exchange of publications is maintained with 404 societies and institutions.

For the twelve months ended 28th February, the number of accessions added to the library was 2,840.

The number of books and periodicals borrowed by members and accredited readers was 365.

During the year new lighting was installed in the library, resulting in much better facilities for reading. Also, the library floors have been thoroughly cleaned and arrangements made with Mr. Daly, the caretaker, for regular cleaning in future.

To meet present conditions, the regulations governing the borrowing of journals, etc., were altered. The amended regulations were circularized to members.

Disposal of Surplus Journals and Books.—A list of about two-thirds of the journals which are duplicated with those in the library of the Linnean Society of New South Wales, and which it had been agreed to dispose of by sale, was compiled and circulated in Australia and overseas requesting offers for their purchase. To date offers amounting to approximately £1,700 have been received. Considerable care was taken in compiling the list, which contains the full titles

of the journals, the exact volumes available, with their dates, and those which were bound.   As a result, interested persons have been able to state immediately their requirements without further correspondence.   Among the institutions interested in purchasing the journals were the University of New England, the N.S.W. University of Technology, Adelaide Botanic Garden, and English, Dutch and American booksellers.

The Director of the Agricultural Research Institute, Wagga, wrote enquiring whether the Society had any agricultural publications it wished to dispose of.   A list containing agricultural publications, both for sale and donation, was prepared and sent to the Director, resulting in a sale of periodicals to the Institute amounting to £71 15s.

Sales of books to institutions and private persons amounted to £23 19s.

Revision of the library catalogue has continued, and new and amended entries have been sent to Pitt's catalogue in order to keep our entries up to date.

Among the institutions which made use of the library through the inter-library scheme were C.S.I.R.O. Coal Research Station, Head Office, Melbourne, McMaster Animal Health Laboratory, Division of Fisheries, Division of Industrial Chemistry, Wool Textile Research Laboratories, Animal Genetics Section, Division of Entomology, Division of Plant Industry, Division of Food Preservation, Tasmanian Regional Laboratory, Regional Pastoral Laboratory, Armidale, Regional Pastoral Laboratory, Deniliquin, Commonwealth Research Station, Irrigation Research Station, National Standards and Radiophysics Laboratory, Colonial Sugar Refining Co. Ltd., Sydney Technical College, University of Melbourne, Fisher Library, University of Sydney, Forestry Commission of N.S.W., Division of Wood Technology, Australian National University, Royal Society of Tasmania, N.S.W., Department of Agriculture, Commonwealth Observatory, University of Queensland, Faculty of Veterinary Science, University of Sydney, Newcastle Technical College, Wollongong Technical College, W. D. and H. O. Wills, Ltd., Melbourne Public Library, S.M.H.E.A., University of Adelaide, University of Tasmania, Dental Hospital, Sydney, Waite Agricultural Research Institute, Australian Museum, M.W.S. and D. Board, Bureau of Mineral Resources, Queensland Institute of Medical Research, N.S.W. Department of Health, Standard Telephones and Cables Ltd., N.S.W. University of Technology, Sydney County Council, Patent Office, Canberra, South Australian Museum, Australian Atomic Energy Commission, Department of Labour and National Service, Sydney, Queensland Department of Agriculture, Coal Research (Pty.) Ltd., Public Hospital, Auckland, N.Z., Victoria University College, Wellington, N.Z.

IDA A. BROWNE,
Vice-President.

THE ROYAL SOCIETY OF NEW SOUTH WALES.

BALANCE SHEET AS AT 28th FEBRUARY, 1955.

LIABILITIES.

1954. £		1955. £ s. d.	£ s. d.
148	Australian and New Zealand Bank Ltd.—Overdraft		383 2 9
33	Accrued Expenses		—
29	Subscriptions Paid in Advance		39 6 0
124	Life Members' Subscriptions—Amount carried forward		114 12 0
	Trust and Monograph Capital Funds (detailed below)—		
	Clarke Memorial	1,869 18 0	
	Walter Burfitt Prize	1,089 8 9	
	Liversidge Bequest	716 3 1	
	Monograph Capital Fund	3,941 8 9	
7,431			7,616 18 7
23,644	ACCUMULATED FUNDS		22,913 10 4
	Contingent Liability (in connection with Perpetual Lease.)		
£31,409			£31,067 9 8

ASSETS.

1954. £		1955. £ s. d.	£ s. d.
4	Cash at Bank and in Hand		6 11 10
	Investments—		
	Commonwealth Bonds and Inscribed Stock, at Face Value—		
	Held for—		
	Clarke Memorial Fund	1,800 0 0	
	Walter Burfitt Prize Fund	1,000 0 0	
	Liversidge Bequest	700 0 0	
	Monograph Capital Fund	3,000 0 0	
	General Purposes	2,460 0 0	
9,360			8,960 0 0
	Debtors for Subscriptions	115 6 0	
	Less Reserve for Bad Debts	115 6 0	
14,835	Science House—One-third Capital Cost		14,835 4 4
6,800	Library—At Valuation		6,800 0 0
385	Furniture—At Cost—*less* Depreciation		442 13 6
22	Pictures—At Cost—*less* Depreciation		21 0 0
3	Lantern—At Cost—*less* Depreciation		2 0 0
£31,409			£31,067 9 8

TRUST AND MONOGRAPH CAPITAL FUNDS.

	Clarke Memorial.			Walter Burfitt Prize.			Liversidge Bequest.			Monograph Capital Fund.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Capital at 28th February, 1954 ..	1,800	0	0	1,000	0	0	700	0	0	3,000	0	0
Revenue—												
Balance at 28th February, 1954 ..	9	10	7	55	14	9	20	17	6	844	19	7
Income for twelve months ..	60	13	2	33	14	0	23	11	7	103	7	0
	70	3	9	89	8	9	44	9	1	948	6	7
Less Expenditure		5	9		—		28	6	0	6	17	10
Balance at 28th February, 1955 ..	£69	18	0	£89	8	9	£16	3	1	£941	8	9

ACCUMULATED FUNDS.

		£	s.	d.
Balance at 28th February, 1954		23,644	4	4
Less—				
Increase in Reserve for Bad Debts..	£3 19 0			
Bad Debts written off	6 6 0			
Loss on Sale of Inscribed Stock ..	20 15 0			
Deficit for twelve months (as shown by Income and Expenditure Account)	331 4 0			
Refund to A.N.R.C. *re* Perpetual Lease	368 10 0			
		730	14	0
		£22,913	10	4

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of The Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on the 28th February, 1955, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Per Conrad F. Horley, F.C.A. (Aust.),
Chartered Accountants (Aust.).

Prudential Building,
39 Martin Place,
Sydney, 15th March, 1955.

(Sgd.) C. J. MAGEE,
Acting-Honorary Treasurer.

INCOME AND EXPENDITURE ACCOUNT.

1st MARCH, 1955, to 28th FEBRUARY, 1955.

1953-4. £		1954-55. £ s. d.	£ s. d.
31	To Audit		31 10 0
76	,, Cleaning		87 2 6
22	,, Depreciation		25 18 2
36	,, Electricity		43 10 3
3	,, Entertainment Expenses..		2 2 3
12	,, Insurance		23 12 1
69	,, Library Purchases and Binding		217 13 8
89	,, Miscellaneous		141 10 2
101	,, Postages and Telegrams		134 5 11
	,, Printing and Binding Journal—		
	Vol. 87, Parts 3 and 4	442 13 9	
	Title Pages and Lists of Contents, Vols. 83, 85 and 86	33 0 0	
752			475 13 9
130	,, Printing—General		127 2 10
37	,, Rent—Science House Management		51 6 7
20	,, Repairs		60 8 8
992	,, Salaries		1,046 9 10
—	,, Symposium		11 2 6
31	,, Telephone ..		29 1 2
£2,401			£2,508 10 4

1953-4. £		1954-55. £ s. d.	£ s. d.
939	By Membership Subscriptions		874 13 0
11	,, Proportion of Life Members' Subscriptions ..		9 9 0
400	,, Government Subsidy		450 0 0
200	,, Commonwealth Bank—Special Grant		—
450	,, Science House Management—Share of Surplus		410 15 0
109	,, Interest on General Investments		82 18 6
29	,, Reprints		222 2 4
103	,, Other Receipts—Sale of Periodicals *ex* Library		122 0 0
	,, Annual Social Function—		
	Amount Received	46 17 6	
	Less Expenditure ..	41 9 0	
25			5 8 6
185	,, Deficit for Twelve Months		331 4 0
£2,401			£2,508 10 4

ABSTRACT OF THE PROCEEDINGS

OF THE SECTION OF

GEOLOGY

Chairman : J. A. Dulhunty, D.Sc.
Honorary Secretary : R. D. Stevens.

Meetings.—Nine meetings were held during the year, the average attendance being twenty-two members and visitors.

April 21st.—Address by Professor C. Osborne Hutton on " Mineralogical Research at Stanford ".

May 21st.—(*a*) Address by Mr. R. Jones on " Scenery and Geology in the Northern Flinders Ranges, South Australia ". (*b*) Dr. G. D. Osborne exhibited serpentinized harzburgite from Wood's Reef, near Barraba. (*c*) Mr. N. C. Stevens noted granitization phenomena at Wyangala Dam, illustrated with colour slides, and exhibited Tertiary leaves from between Cargo and Cudal. (*d*) Mr. C. T. McElroy exhibited Hawkesbury and Narrabeen sandstones, suggesting the terms " petromictic "—or " lithic "—sandstone for the latter.

June 18th.—Address by Dr. Hari Narain on " Gravity Investigations to Delineate Structural Trends in Queensland ".

July 16th.—Address by Dr. W. R. Browne on " ' Greybilly ' and Some of Its Implications ".

August 20th.—(*a*) Dr. W. R. Browne exhibited sandstone with sideritic cement from Warragamba and noted distribution and origin of jointing near Warragamba Gorge. (*b*) Dr. L. E. Koch exhibited vivianite from the Cobargo District. (*c*) Mr. L. J. Lawrence exhibited uranium-bearing allanite rock, skarn, hornfels, davidite in calcite and brannerite from the Mt. Isa-Cloncurry District. (*d*) Mr. R. D. Stevens exhibited Tertiary plant remains from Mt. Jellore and discussed the origin of joint systems in the Mittagong District. (*e*) Dr. G. D. Osborne exhibited tourmalinized quartzitic rock from Glenrock Estate, Marulan ; and tourmaline schist from Black Hills, South Dakota.

September 17th.—(*a*) Address by Messrs. G. H. Packham and N. C. Stevens on " Palæozoic Stratigraphy in the Foothills of Mt. Canoblas ". (*b*) Mr. R. D. Stevens exhibited a specimen and thin section (by projection) of dolerite-containing quartzite xenoliths with reaction rims from Mt. Flora.

October 15th.—(*a*) Address by Mr. L. J. Lawrence on " Uranium Mineralization in the Mt. Isa-Cloncurry District ". (*b*) Address by Mr. R. G. Burdon on " The Processing of Uraniferous Ores ".

November 19th.—(*a*) The resignation of the Hon. Secretary, Mr. R. D. Stevens, was accepted with regret. Mr. H. G. Golding was elected Hon. Secretary for the remainder of the year. (*b*) Dr. G. D. Osborne exhibited a specimen showing slump bedding in Upper Kuttung siliceous varve-rock from the Patterson-Seaham District. (*c*) Mr. H. G. Golding exhibited specimens and photographs of zoned concretions containing millerite from Narrabeen beds near Gosford. (*d*) Dr. T. G. Vallance exhibited colour slides illustrating geology in the vicinity of the Highland Boundary Fault. (*e*) Miss Parker exhibited colour slides illustrating physiography of west and north-west United States.

March 18th.—(*a*) Dr. W. R. Browne gave a short talk on the need for studying the Tertiary and post-Tertiary Geology of the State. (*b*) Dr. G. D. Osborne noted Pleistocene or Recent deposits on Illawarra Line, N.S.W. ; and Tertiary or later sediments at Long Bay, N.S.W., exhibiting slides of the latter occurrence. (*c*) Mr. L. J. Lawrence exhibited quartz overgrowths, cassiterite and adularia on quartz, cassiterite in granite and cassiterite entirely replacing quartz, from the Torrington District, N.S.W. (*d*) Dr. T. G. Vallance exhibited a William Smith geological map of Buckinghamshire. (*e*) Dr. L. E. Koch exhibited vivianite-bearing deposits from the Cobargo District, N.S.W., and colour slides of the occurrence and noted aspects of the instability, genesis and pastoral significance of the vivianite. (*f*) Mr. H. G. Golding exhibited barite discs and a discoidal concretion from the Gosford District, N.S.W.

Obituary

HORATIO SCOTT CARSLAW. The death occurred on 11th November, 1954, at the age of eighty-four, of Horatio Scott Carslaw, Emeritus Professor in the University of Sydney, and Fellow of Emmanuel College, Cambridge, Professor of Mathematics in the University of Sydney during 1903–1935. Carslaw held the degree of Doctor of Science of Glasgow and Cambridge, and the honorary degree of Doctor of Laws of Glasgow.

Carslaw served the University of Sydney through a period of great expansion. He had precisely that balance of qualities which best fit a man to raise a small department, not very different from a " sixth form ", to a university school of mathematics with a world-wide reputation for its published work and for the quality of its graduates. He had a vigorous personality of the type around which legends collect, he was a mathematical scholar of distinction with a gift for clear exposition, and he was enthusiastic in his mathematics and aroused enthusiasm in his students.

Five papers were published in the " Journal and Proceedings " of this Society. Professor Carslaw was a member since 1903, and a member of the Council for the 1916–1917 session.

In 1907 Carslaw married Ethel Maude, the daughter of Sir William Clark, but she died within the year. Thereafter Carslaw took little part in the social life of the University of Sydney ; but he contributed with his characteristic vigour and vivacity to all other phases of university activity.

SIR FREDERICK DUNCAN MCMASTER died at his home at Dalkeith Station, Cassilis, N.S.W., on 28th November, 1954. He was one of Australia's best known pastoralists, and a prominent stud-master. One of his main interests was breeding merino sheep, and he gradually built up the world-famous Dalkeith Stud. He was a prominent member of the Royal Agricultural Society of New South Wales and also an honorary life member of the Royal Agricultural Society of England.

Sir Frederick presented £20,000 for the erection of a laboratory for the investigation of animal health problems, known as the McMaster Animal Health Laboratory, for the Commonwealth Council for Scientific and Industrial Research at the University of Sydney. A great deal of invaluable research has been done at this laboratory. When it became known to Sir Frederick in recent months that the McMaster Laboratory was in urgent need of additional space, he arranged for Commonwealth bonds to the value of £52,800 to be made available to the University of Sydney for the erection of a wing to the Laboratory.

Sir Frederick was born in 1873, and was educated at the Sydney Grammar School. In 1934 he was created a Knight Bachelor in recognition of his great services. By his death Australia has lost a great pastoralist, a keen supporter of scientific work, and a generous benefactor.

GEORGE WRIGHT died on 18th May, 1954, at the age of seventy-seven. Mr. Wright was associated all his life with the retail trade, and joined Farmer & Co. Ltd. as a director in 1912. He retired as managing director of the company in 1938, but continued on the board and was chairman of the company in 1948–1949.

Mr. Wright took a prominent part in charitable movements, and for many years was chairman of the Burnside Presbyterian Homes for Children.

JAMES P. HILL died very suddenly at his home in London on 24th May, 1954. He was born in 1873. In 1892 Dr. Hill was a Demonstrator in Biology at the University of Sydney, and Lecturer in Embryology there in 1904. From 1921 to 1938 he was Professor of Embryology at London University. He was elected to the Royal Society in 1913 and awarded the Darwin Medal in 1940.

The list of publications by Dr. Hill extends over a long period, from 1892 to 1947, and is evidence of a life of continuous study and careful observation of morphological and developmental problems.

His comparative knowledge of the animal kingdom, both invertebrate and vertebrate, was outstanding. He was a great teacher, and a patient demonstrator. A series of notebooks in which the details of every embryo were meticulously recorded form an invaluable guide to his extensive collection.

His high distinction as an embryologist is universally recognized and, in 1948, Volume 82 of the *Journal of Anatomy* was dedicated to him.

FREDERIC WOOD JONES died in London on 29th September, 1954. He was one of the leaders in contemporary scientific thought, not only in his own field of human anatomy and physical anthropology, but also in the wider field of comparative vertebrate morphology. He maintained a broad biological outlook from the beginning of his working life until the end.

He was born in London on 23rd January, 1879. In 1919 he made his first contact with Australia, when he was appointed to the Elder Chair of Anatomy at the University of Adelaide. Late in 1926 he resigned his Chair in Adelaide, but returned to Australia in 1930, this time to Melbourne, where he was appointed to the Chair of Anatomy. He resigned from the Melbourne Chair in 1937 and was appointed Professor of Anatomy at Manchester.

During his life Wood Jones received many honours. He was awarded the D.Sc. of the University of London in 1910, and received the same degree from the Universities of Adelaide and Melbourne.

He was appointed a Fellow of the Royal Society in 1925 and a Fellow of the Royal College of Surgeons in 1930. In 1935 he received the Fellowship of the Royal Australasian College of Surgeons. He was also a Fellow of the Zoological Society.

For some years before his death he was Hunterian Trustee of the Royal College of Surgeons and, in 1949, the College awarded him their Honorary Medal, the highest honour they could bestow.

GORDON KINGSLEY HUGHES died suddenly on the morning of 10th February, 1955. He was the second son of the Rev. H. Estcourt Hughes, a leading member of the Baptist ministry in Adelaide. He received his later education at Adelaide High School and the University of Adelaide, where he graduated B.Sc. after a notable undergraduate course, in 1928. In 1929 he proceeded to the B.Sc. honours degree, gaining second-class honours. In 1954 he was awarded the degree of Doctor of Science for his work on the chemistry of natural products. Prior to joining the staff of Sydney University in 1934 as Junior Lecturer, he had acted as a demonstrator in the Chemistry Department at Adelaide University. Since 1944 he held the post of Senior Lecturer in Organic Chemistry, and was Acting Professor of Organic Chemistry in 1946 during the absence of Professor J. C. Earl.

Hughes was a popular figure outside the limits of the Chemistry Department, and gained blues from the University of Adelaide for both cricket and baseball. In recent years he has been a keen bowler, being a member of the North Sydney Bowling Club. He is survived by Mrs. Hughes.

RICHMOND DOUGLAS TOPPIN was born at Warialda, New South Wales, and received his early education at Cleveland Street Public School, Sydney. After leaving school, he attended classes at the Sydney Technical College, and gained the Associateship in Chemistry in 1915. In World War I he served in the Army Medical Corps attached to the Australian Imperial Forces. During his overseas service he was elected to associate membership of the Royal Institute of Chemistry. He founded the firm of R. D. Toppin & Sons, manufacturers of pharmaceutical products and specialists in tablet making. Although the directing force of an active organization, he was an excellent example of the practical, scientifically trained man who could perform every type of job in a manufacturing works. He was closely associated with scientific societies in New South Wales, and became an Associate Member of the Australian Chemical Institute in 1928. At one period he was Honorary Secretary of the Sydney section of the Society of Chemical Industry. He joined the Sydney Technical College Chemical Society in 1920, and was President in 1925. He was elected to membership of the Royal Society of New South Wales in 1938, and published 13 papers in the Society's Journal and Proceedings. He was a member of the Council in 1950–51 and 1951–52. He leaves a widow, two sons and a daughter.

PRESIDENTIAL ADDRESS

By RONALD S. NYHOLM, D.Sc.

PART I. THE SOCIETY'S ACTIVITIES DURING THE PAST YEAR.

It is unfortunate that the address should have to be read this year with your retiring President 12,000 miles away. However, the acceptance last year of a Chair in London required my departure as soon as possible in 1955. At least I am happy to report that the main business of the Society's year had been completed before I left Australia.

It has been in most ways a good year for the Society, even though certain aspects of our development continue to give the Council cause for concern. We shall return to these matters later. The Council's Report which you have just heard summarizes the year's activities, and I would like to touch on certain of these in more detail.

On 18th June, 1954, the Honorary Editorial Secretary, Mr. Hanlon, and I waited on His Excellency Sir John Northcott at Government House, and were most warmly received. His Excellency showed great interest in our activities and in our future plans. We also were honoured by His Excellency's presence at the symposium on " Oil, Australia and the Future ", held on 4th October. We are proud of the fact that we are a Royal Society and are fortunate that our Vice-Regal Patron participates in our affairs.

During the year three discussions were held in place of the popular science lectures. These were well attended and the Council have decided to continue with this activity in 1955, each of the discussions to be held on ordinary monthly meeting nights. An address on " Education in India ", by Mr. Muni Lal, proved most stimulating. I hope this is only the first of similar talks by representatives of Asian countries to the north of us. The brilliant address dealing with poliomyelitis given by Dr. N. F. Stanley unhappily coincided with the influenza epidemic in Sydney, and only a small audience enjoyed the talk of this outstanding research worker. The talks on evolution by Dr. N. Macintosh and Dr. J. M. Rendel were also most stimulating. Monthly meetings have much to interest all folk, and members are assured that speakers present their subjects in a perfectly general way.

The outstandingly successful evening of the year was the Oil Symposium in October. Four good speakers, together with a topical subject, combined to provide a most entertaining evening. The addresses will soon be made available to members. I believe that we have a responsibility to the community to hold more of these informative symposia on topics of current national interest.

Excellent work is being done by our Library. Special credit is due to our Librarian, Mrs. B. Somerville, and Honorary Librarian, Dr. R. C. L. Bosworth.

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The Council and I are most gratified to see the change which has taken place in the Library since Mrs. Somerville took over. The rationalization of our Library continues, and this year over £600 will be received from the disposal of various journals which we do not wish to retain. The long list of institutions which continue to borrow from us bears testimony to the value of our Library.

The Society was pleased to convey its congratulations to those who were honoured by the award of medals and the Liversidge Research Lectureship. All who are familiar with the great work done for the Society by Dr. D. P. Mellor, particularly in his capacity as Editor of the Journal for many years, will rejoice in the award to him of the Society's Medal. The Clarke Medal, which is awarded from time to time for distinguished work in the natural sciences done in, or on, the Australian Commonwealth and its territories, was awarded to Dr. Rutherford N. Robertson for distinguished work in plant physiology, particularly on salt respiration and its relation to respiration, and on the growth and metabolism of fruits. The award of the James Cook Medal to Sir Frank MacFarlane Burnet, F.R.S., was a well deserved honour in recognition of his distinguished services to science and humanity. I was privileged to present the James Cook Medal for 1953 to Sir David Rivett, F.R.S., as my first duty as President. Sir David was for a long time a great inspirer of his colleagues in Australia ; he emphasized the need for freedom in scientific research and for a proper balance between pure fundamental and the more applied research in our research organizations. The Edgeworth David Medal is awarded annually to Australian research workers under the age of thirty-five years for work done mainly in Australia or its territories or contributing to the advancement of Australian science. The award was made to Dr. Eric S. Barnes for outstanding contributions in the field of mathematical science, particularly his work on the geometry of numbers. The Liversidge Research Lecture was also held during the year, and I was privileged to be chairman at the inspiring address given by Dr. M. R. Lemberg, F.R.S.

The Council also extended congratulations to those Australian scientists who were elected to Fellowship of the newly formed Australian Academy of Science. We look forward to collaboration with the Academy of Science in the future.

During the year we lost five ordinary members and two honorary members by death. Professor Carslaw's passing severs another link with the past, for it is to him that we owe so much in the building up of a high standard in mathematics in Sydney. With Sir Frederick McMaster's death we lose one of the few great patrons of science in this country. His vision and generosity were examples to industrial and civic leaders in a country in which so much is left to the State.

During the year the Society's room received a long-overdue redecoration. Visitors to Science House have expressed pleasure at the improvement. The lighting in the office and library has also been improved. The provision of very necessary floor coverings for the library has had to be deferred pending an improvement in our finances.

Unhappily, our membership has again declined over the year, falling from 385 in 1952 to 361 in 1953, down to 354 in 1954. A glance at Figure 1 shows that the 1952 figure was the highest for the past thirty years. Nevertheless, we cannot afford to see our membership decline, and the Council are taking steps to ensure an ever-increasing flow of new members. We should be specially concerned with a flow of young members into the Society. Furthermore, the Society should consider a more active policy of encouraging more business and civic leaders to join our Society. The financial situation is also quite serious. During the year we were fortunate that our annual Government grant of £400 was increased to £500 per annum. We are grateful to the Government for its

interest in our affairs. However, an overall deficit for the year of £   gives us no room for complacency. The ways in which I believe we should tackle this financial problem are discussed in Part II.

During the year we were represented on Science House Management Committee by our Treasurer, Mr. H. F. Donegan, and as Vice-President, Dr. R. C. L. Bosworth. On three occasions your President was invited to meetings when the matter of rents was being discussed. This subject has not yet been finalized, but the Royal Society hopes to benefit substantially when the new rents are finalized. Members will be interested to learn that Mr. H. F. Donegan is now Chairman of Science House Management Committee.
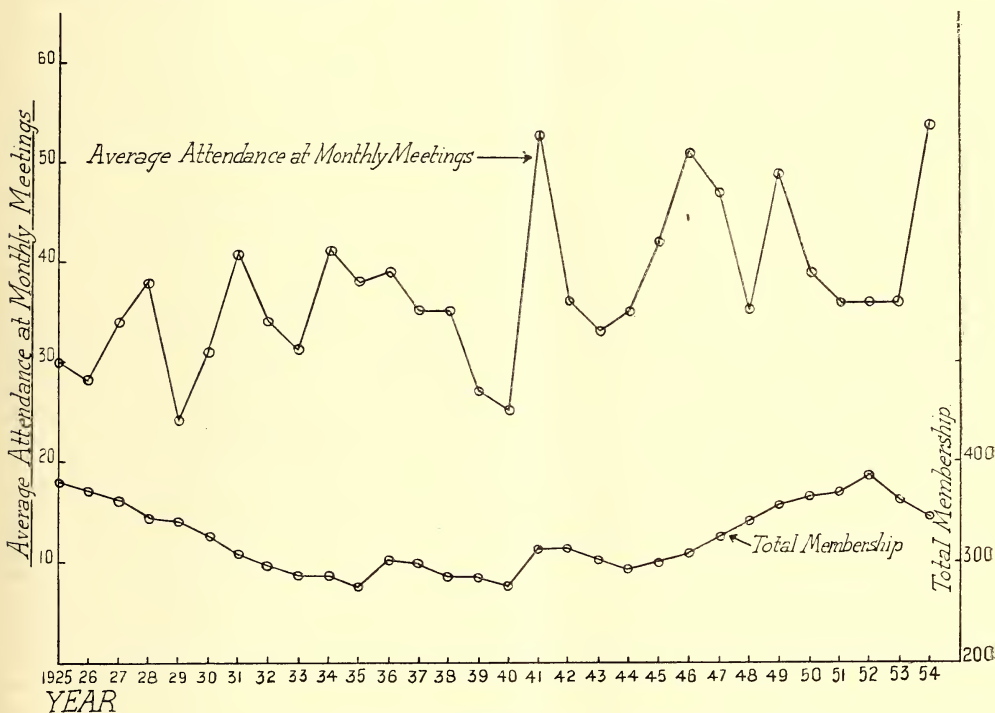
Text-fig. 1.

On the occasion of the commemoration of the landing of Captain Cook at Kurnell, the Society was represented by the President. A wreath in commemoration of Sir Joseph Banks was placed on the memorial by our Society.

During the year Professor Bosson was forced to resign from the secretaryship owing to illness. We are glad to see him active again. Mr. J. L. Griffith was appointed by the Council to this position, and he has been a great help to me personally. I would also like to accord my thanks to Mr. Hanlon, Editorial Secretary, and all members of Council for their generous help at all times. It is a special pleasure to acknowledge the willing assistance of Dr. Phyllis Rountree and Dr. Ida Browne. Dr. Browne has the interests of the Society always uppermost in her mind, and I have received continual assistance at all times from her. Finally, I would like to thank our permanent Secretary, Miss Ogle, for her help throughout the year. I think it most fitting that all members should know of the service rendered by our staff, and in Miss Ogle we have a particularly capable and hard-working officer.

PART II. THE AIMS, OBJECTS AND FUTURE OF THE SOCIETY

It is essential for us to take stock periodically of the development of our Society and to enunciate the policy for the future. The rapidly changing scientific environment in Australia during the past few years makes such an examination of special importance at the present time. During 1953, certain alarming trends became more marked, and Council gave attention to these at a special meeting. Again in 1954 the Council spent a lot of time discussing our objects and our future policy.

1. The Journal and Publication.

The most outstanding change is the rapid dwindling of the number of research papers submitted for publication by the Society. If this were purely temporary, there need be no cause for alarm, but a considerable number of people are convinced, and I number myself amongst them, that in many branches of science, notably chemistry, we shall not see the return to our Journal of many of the *type* of papers which had been coming to us before 1948. To understand this I believe we should look at the history of the development of the Society.

Broadly speaking, the history of the Society falls into three periods. Before the first world war the Royal Society of New South Wales was the main scientific society in Sydney, at least so far as the physical sciences were concerned. The Society was, for scientific people, an important means of mutual contact, discussion and the Journal received many of their original researches. Between the two world wars there were founded in Sydney many specialist scientific bodies or branches of older ones, such as the Institute of Physics and the Royal Australian Chemical Institute, the meetings of which catered for discussions of specialist subjects. Nevertheless, many of the original papers of these specialists still found their way to our Journal. Thus, the 1940 Journal was one of the largest ever, and in it were 38 research papers. There were 23 chemistry papers, 4 in mathematics and 9 in geology.* After the second world war we enter the third phase—the development in Australia of new specialist journals to cater for the needs of scientists. Examples of these are the *Australian Journal of Chemistry* and the *Australian Journal of Physics*. Furthermore, overseas societies publishing specialist journals, e.g. the Chemical Society of London, speeded up the rate of handling of papers and went out of their way to provide air-mail facilities in order to assist folk submitting papers from Australia. Some say that the long delay in the publication of our Journal just after the war was a major reason for workers transferring their work elsewhere. Let me hasten to emphasize that these delays were in no way the fault of the Society, but arose from difficulties on the part of our publishers. Whatever may have precipitated the transfer elsewhere, there is little doubt that, having moved to a specialist journal, many authors are reluctant to return to publishing in our Journal.

The decline in the number of research papers received (as distinct from the Presidential Address, Clarke and Liversidge Lectures) is shown in Figure 2. The rapid decline since 1948–1949 both in the number of research papers published and in the number of pages in the Journal is all too obvious. The good correlation between the number of pages in the Journal and the number of research papers is noteworthy. The size of the Journal was the smallest in 1952 since 1929. (See Fig. 2.)

This brings in its wake several problems. Firstly, our Journal is becoming unbalanced ; we are fortunate in still receiving many excellent papers in geology, but in chemistry and physics they have dwindled away almost to nothing. Eventually this will almost certainly affect our exchange scheme, whereby we

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* For the 1952 Journal the corresponding figures are 2, 0 and 8.

receive other journals in return for our own. It seems unlikely that societies overseas producing a specialist journal in chemistry of some thousand pages or more will be happy to exchange with us for a journal of 100–200 pages and containing only one or two chemistry papers. Also, members will begin to feel that there is less and less to interest them in the Journal and membership may suffer. I believe that we must keep our Journal very much alive as a medium for the publication of original research : firstly, for exchange purposes and for the benefit of members as something tangible which they receive ; secondly, to fulfil one of our main objects—that of publishing original researches ; thirdly, to ensure that come what may in other specialist journals there always exists a more general type of research journal available for papers which are more of a borderline type.
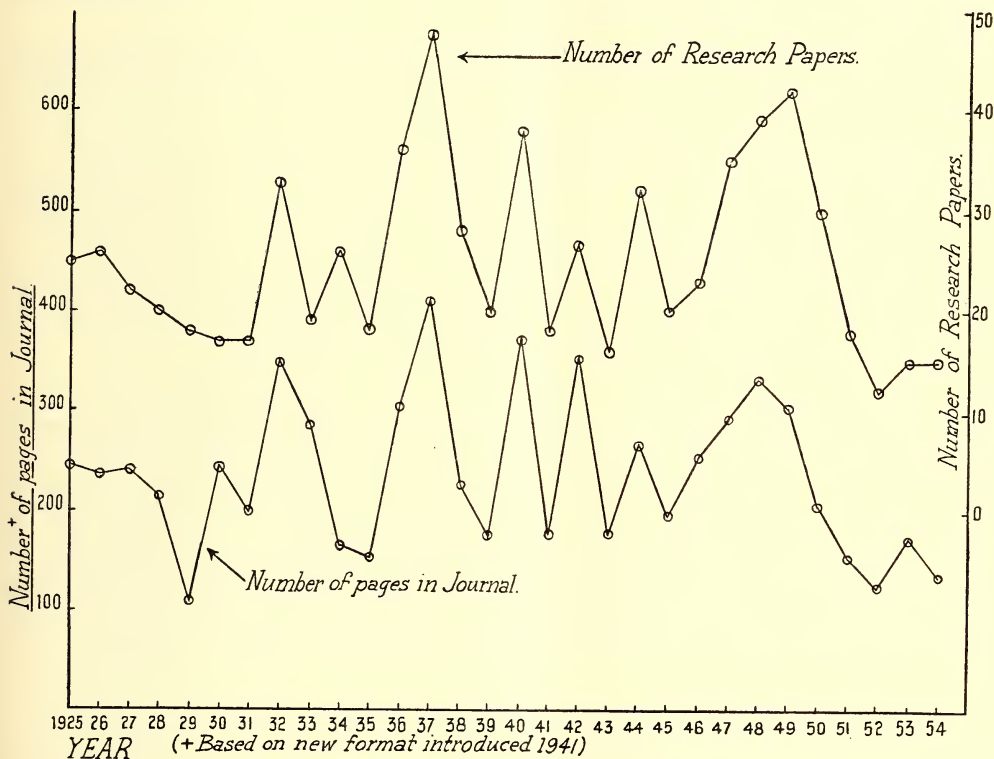
Text-fig. 2.

To restore and maintain a flow of papers in all branches of the physical sciences means that we must provide some kind of stimulus. I am much attracted to a proposal from one of our former Presidents, Dr. R. C. L. Bosworth. We all know that the average paper in a specialist journal is written for the expert. Thus, Part X of a series of papers, say, on paramagnetic resonance, for example, is quite incomprehensible to workers other than those engaged in this field, unless previous papers and indeed the background to the subject is studied. Dr. Bosworth suggests that we encourage authors to submit more papers which can be read by the ordinary graduate. I quote from Dr. Bosworth's letter :

"Tradition and custom in specialist journals in physical sciences, much more so than in natural sciences, demands that the author address himself to an audience which is assumed to be as familiar with the literature of his specialist subject as he is himself. This custom, while it may ensure

the author's paper getting as speedily as possible into the hands of those few people who are most important to his professional advancement, effectively isolates his paper—at least until it is reinterpreted in a review article elsewhere—from the much larger circle of potential readers who would like to know, without following details of the investigation, what his work is about, what relation, if any, it bears to their own science and what are the prospects of building on it some form of technical advancement.

" Professional stature in science is, I believe, not necessarily synonymous with incomprehensibility and in many instances the report on a scientific advance can be worded in such a way as to be reasonably intelligible to anyone who has taken the trouble to read, say to the pass standard, in discipline involved, without losing in one iota its claim to be a report on a advance of the highest rank.

" I would suggest that we deliberately adopt as a policy the encouragement of this style of publication, offering to authors and prospective authors the opportunity of presenting their work in a form which would be available to a wider circle of readers than the specialized journals and offering to readers a journal where it will not be necessary to hunt back through too many earlier publications before grasping the essential point of a recorded advance in science.   I would, however, like to make it clear that what I am asking for is more wordy introductions in which the relation between the work recorded and existing knowledge is carefully explained, more carefully developed arguments and a more skilful summing up of the findings—all of which will add up to a higher cost of publication per paper ; but perhaps this is unavoidable if we are to retain the journal."

This proposal is worthy of careful study.   We should encourage our authors to submit periodically to our Journal a part of their work and give in some detail a fuller explanation of the background of the work, its importance and possible implications.   In addition to our Journal, which I believe should be restricted mainly to research papers and special lectures, I believe we should publish separately in brochure form many more of the symposia and discussions which we hold.   This has been done in the past, but we must do so more frequently. These should be of considerable interest to all members and to the general public. Members will be receiving more for their contribution to the Society, and our activities will become more widely known throughout the community.

2. The Needs of Members.

Important as our research publications are, and prized as our medals may be, it must always be remembered that the Royal Society of New South Wales contains a large number of people whose interests lie elsewhere than in the particular papers published in the Journal.   Thus, a social scientist may well find that there may not be a single paper in his field published during the whole year.   I believe that we must make monthly meetings of living interest to *all* of our members by making these as general as possible.   This does not mean descending to a low level in science, but rather the discussion of either borderline subjects or topics of current interest from several points of view.   Various symposia have been held at different times by the Society, and they are usually very successful.   A symposium on Fluorine some years ago, arranged by Dr. Mellor, attracted over a hundred people.   This symposium was subsequently published.   This year we have again found the hall filled when such a symposium was held.   We have now arranged for the regular discussions to be held on ordinary monthly meeting nights because the number of meetings per month is becoming excessive for most people.   These discussions are open to the general

public ; by occasionally inviting the public to our meetings we publicize more widely our activities. Finally, I must emphasize again that we should publish these discussions whenever possible.

III. The Royal Society and the Community.

Our Society must always bear in mind that we have a responsibility to the community to interpret scientific developments and to report objectively on controversial subjects which industrial organizations and government bodies are more reluctant to examine. The Royal Society needs to lead wherever it can. I believe that by showing the Government that we are accepting these responsibilities and examining national issues in such a way as to enlighten the public we will receive even greater financial support than in the past. Challenging issues such as " Can Australia Feed Her People in the Future ? ", " The Future of Coal as a Fuel " give us an opportunity to inform our members and the public. By so doing I believe we shall influence many more business folk and leaders in civic and political life to join our Society.

4. Balancing Our Budget

In Part I, I referred to the steady succession of financial deficits of our Society since 1949. The actual figures are :

Year.				Amount of Deficit.		
				£	s.	d.
1947–48	..	..	..	81	11	4
1948–49	..	..	..	—		
1949–50	..	..	..	436	3	7
1950–51	..	..	..	686	13	0
1951–52	..	..	..	736	1	1
1952–53	..	..	..	212	8	8
1953–54	..	..	..	184	12	8
1954–55	..	..	..	331	4	0

Fortunately, to meet the deficiency so far we have been able to draw upon capital funds in the nature of bonds purchased some years ago when surpluses were the norm each year. This procedure can be justified only as a temporary measure, and obviously cannot continue if the deficits continue each year. It seems quite clear that drastic steps must now be taken to remedy this situation. I regard any suggestion that we should curtail our activities, e.g. decrease our publishing or surrender area which we are at present renting, as fatal. This would merely accelerate our passing as an honoured scientific body. Rather, I believe our publishing and public activities must increase if we are to survive as an active society. To do this we must in fact *increase* our annual expenditure. This means that our income should be increased by an amount between £1,000 and £2,000 per annum. I believe that if we actively pursue the lines suggested below this amount will be forthcoming. However, it will only be forthcoming if the sources upon which we hope to draw are really convinced of the renewed drive and activity of the Society and of its increased value to members, the community and to science generally. In short, before pressing forward towards the following objectives we ought first to be clear on our future policy ; this policy should be proclaimed publicly, and, finally, concrete evidence of our expanding activities should be available to put before those whom we seek to impress. When this has been done I believe we can expect to gain the increased finances from the following sources :

(1) Increased rents from Science House. These will soon be decided and should amount to several hundred pounds per annum.

(2) Increased Government grant. Our very favourable reception at our last visit to the Minister for Education was most encouraging. Once concrete evidence of our future activities is put before the Minister, I confidently predict that our grant will be considerably increased and I believe that we should aim at an annual government grant of £1,000 per annum.

(3) Greater return from our premises. Subject always to the proviso that our rooms remain under our control, I believe that we could obtain quite a substantial revenue by arranging for certain of our rooms to be used by other organizations. Discussions on this matter are in progress in the Council.

(4) Special grants. I believe that, armed with effective proof of the value of our activities and our publications, annual approaches should be made to the Rural Credits Development Fund, business organizations and semi-government institutions for funds.

(5) Increased membership. Finally, as soon as we can present our new activities and publications to possible new members, a full-scale recruitment drive should be launched. I believe that in addition to the very important personal acts of recruitment by our members—particularly those teaching university students—the following should be considered :

    (a) The sending of letters of invitation to join our Society to prominent government, civic, business, medical and scientific people not at present members. In the case of the civic and business people the prestige and value of the Royal Society to the community should be stressed.

    (b) Increased recruitment of students graduating in science each year from the two universities in Sydney should be attempted by sending each of these a personal letter of invitation to join. This should be accompanied by a suitable explanatory brochure, together with a typical monthly notice paper showing just what kind of meetings we hold.

The Royal Society of New South Wales has done great work in the past ; a change in things around us simply means that we must re-interpret our objects in the light of these changes. It is my firm conviction that, by facing up to these changes, we can assume an even greater role of leadership in the future.

PART III. MAGNETISM AND STEREOCHEMISTRY.

INTRODUCTION.

The past twenty years have seen great advances in inorganic chemistry. During this period the subject has changed from an essentially preparative one into a branch of chemistry which is concerned with the preparation, properties, reactivity and structure of the compounds of elements other than carbon.

This change in outlook in inorganic chemistry is due mainly to the application of quantum mechanics and physical methods of investigation. A particular example of this development is the greatly increased application of magnetic susceptibility measurements. In this survey the kind of information which may be inferred from magnetic measurements will be summarized, and the application to stereochemistry in particular will be discussed at length. As an essential preliminary we shall first outline the fundamentals of magnetochemistry as required for the subsequent discussion. In this survey we shall be concerned primarily with the value of paramagnetism.

PRINCIPLES OF MAGNETISM*

It is well known that elongated crystals of certain naturally occurring substances when freely suspended in a horizontal plane orient themselves in a north-south direction. This behaviour occurs because the crystals are themselves " permanent " magnets which tend to orient themselves in the direction of the earth's weak magnetic field. A rod of iron will show the same behaviour if stroked with a magnet in the same direction several times or if allowed to remain in a magnetic field for a long time.

For practical purposes the behaviour of such a magnetized rod can be interpreted as arising from the presence of two magnetic " poles ", one near each end of the rod. These " north " and " south " poles, named in accordance with the particular geographic pole which they are seeking, cannot be separated from the rod, but by choosing a rod of sufficient length the behaviour of one pole may be studied with little effect from the other. It is found that like poles repel one another and unlike poles attract, the force between them varying inversely as the square of the distance between the poles. This is used to define " pole strength ", a *unit pole* being one which repels a similar and equal pole at a distance of 1 cm. *in vacuo* with a force of one dyne. For poles of strength M_1 and M_2, this leads to the expression $F = \dfrac{M_1 M_2}{d^2}$ *in vacuo*, F being the force in dynes and d the distance between the poles in cm. In general, the force between two poles is altered by interposing between them any solid, liquid or gaseous material. The force is then given by the expression $F = \dfrac{M_1 M_2}{\mu d^2}$ where μ† is known as the *magnetic permeability* of the material.

A magnetic field exists in the vicinity of a magnetic pole and its *intensity* (H) at a particular point is measured by the force which would act upon unit north pole if placed at that point. If this force is 1 dyne, the magnetic field is one of unit intensity. The unit of magnetic intensity is known as the oersted.‡ Magnetic intensity is a vector quantity since it has both magnitude and direction. It is conveniently represented by " lines of force " which give both the direction of the field and its intensity by adopting the convention that one oersted equals one line of force per sq. cm. The number of lines of force emanating from unit pole follows from the fact that the magnetic intensity everywhere over the surface of a sphere at a distance of 1 cm. from unit pole is 1 oersted ; since the surface area of a sphere of radius 1 cm. is 4π cm^2, the total number of lines of force must be 4π.

For a bar magnet, the product of the pole strength (m) and the distance between the two poles (l) is called the *magnetic moment*. It is a most important quantity in the theory of magnetism. No macro unit of magnetic moment is in use, but on the atomic scale the Bohr magneton is a convenient unit. This will be defined later. The *magnetic moment per unit volume* (often called the *intensity of magnetization*) is denoted by the symbol I. A specimen of length l and cross sectional area A having an intensity of magnetization I is equivalent to a magnetic dipole consisting of two poles of strength IA at a distance of l cm. apart. If a substance be placed in a magnetic field of strength H oersteds *in vacuo*, then the magnetic field inside the material, the magnetic induction B, is given by the expression $B = H + 4\pi I$. This can be shown simply by considering a cylinder of the material of length and cross sectional area A placed lengthwise

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* No attempt will be made to give a detailed introduction here. The reader is referred to books and reviews shown in the list of references. These are indicated by an asterisk.

† Not to be confused with *magnetic moment*, discussed presently, for which the same symbol is used.

‡ Formerly known as the gauss. This is now reserved for magnetic induction only.

in the field H. If a narrow transverse cut be now made in the rod, the number of magnetic poles/sq. cm. on each side of the gap equals I. The 4π lines of force from *each* pole *all* cross the gap, and hence the number of lines of force in the gap in addition to those arising from the field H is $4\pi I$. Hence, the total number of lines of force (B) is given by the expression $B = H + 4\pi I$. Dividing through by H, we obtain $\frac{B}{H} = 1 + 4\pi\frac{I}{H}$. The ratio $\frac{I}{H}$ is called the magnetic susceptibility per cubic cm. of the material, commonly known as the *volume susceptibility* and denoted by the symbol k. The ratio B/H is the magnetic permeability of the material μ. It is the same quantity as that found in the expression for the force between two poles. We thus have the expression $\mu = 1 + 4\pi k$. In an experimental determination it is k which one usually measures.

Chemical substances may be divided into three main classes* in accordance with the magnitude of their susceptibilities. If k is negative, the substance is called *diamagnetic*. When k is positive and small, the substance is *paramagnetic*, whilst if k is positive and large and varies with the field strength and previous history of the specimen then the substance is *ferromagnetic*.

For chemical work, k is used less frequently than χ, the *susceptibility per gramme*. χ is related to k by the expression $\chi = \frac{k}{\rho}$, where ρ is the density in grammes/c.c. Of special importance are the *gramme-atom* (χ_A), *gramme-ion* (χ_{A+} or χ_{B-}) and *molar* (χ_M) susceptibilities ; these are derived by multiplying the gramme susceptibility χ by the *atomic weight*, *ionic weight* or *molecular weight* respectively of the compound in question. Table 1 gives a few susceptibilities to give some idea of the size of these quantities.

TABLE 1.

Magnetic Susceptibilities at 20° C.

Substance.	Value of $\chi \times 10^{-6}$	Value of χ_M or χ_A $\times 10^{-6}$	Comment.
Mercury	$-0\cdot19$	$-30\cdot0$	A diamagnetic element.
KCl	$-0\cdot52$	$-38\cdot7$	A diamagnetic salt consisting of a mixture of two diamagnetic ions.
H_2O	$-0\cdot72$	$-13\cdot0$	A diamagnetic compound.
$CuSO_4.5H_2O$	$5\cdot9$	1480	A weakly paramagnetic compound containing one unpaired electron.
K_3FeF_6	$62\cdot5$	14995	A strongly paramagnetic compound containing five unpaired electrons.
Specimen of soft iron at $H = 50$ oersteds	$2\cdot5$*	—	A strongly ferromagnetic element.

* Not $\times 10^{-6}$.

Energetics of Magnetization.

Consider a cylinder of length l and cross sectional area A. Apply a steadily increasing field such that when this reaches the value H the intensity of magnetization is I. For a small increase δH in field strength let I increase to $I + \delta I$. This results in new poles of strength $A\,\delta I$ appearing at both ends. The work done on the system is equal to that evolved when these new poles are

* Other subdivisions will be referred to later.

transported from one end of the cylinder to the other against the field H. Since the force is $HA\delta I$, the work done is $lHA\delta I$. Since $lA =$ volume of specimen, V the element of work done, $= VH\delta I$ ergs. Hence, the total work done in increasing the intensity of magnetization from 0 to I is $V\int_0^I HdI$, whilst the energy stored per UNIT volume of the material is $\int_0^I HdI$. This expression can be simplified if we are dealing only with diamagnetic and paramagnetic (non-ferromagnetic) materials for which the ratio $\dfrac{I}{H}$ is a constant equal to the volume susceptibility k_1. We can substitute $k_1 H$ for I. Then the total energy stored in a specimen of volume V is

$$k_1 V \int_0^H HdH = \tfrac{1}{2}k_1 H^2 V \text{ ergs.}$$

If, however, the susceptibility of the surrounding medium is k_2 the energy possessed by the same volume of the medium is $\tfrac{1}{2}k_2 H^2 V$. Hence, the potential energy of the magnetized material in the medium is $\tfrac{1}{2}(k_1 - k_2)H^2 V$ ergs.

Consider now a small specimen of volume v in a non-uniform magnetic field.* Any force on the specimen will be in such a direction as to tend to reduce the potential energy. If this force is F, the work done in a small displacement δx is $F\delta x$. This must equal the change in potential energy of the system, i.e. $\tfrac{1}{2}(k_1 - k_2)v\delta(H^2)$

$$\text{i.e., } F\delta x = \tfrac{1}{2}(k_1 - k_2)v\delta(H^2)$$

$$\text{whence } F = \tfrac{1}{2}(k_1 - k_2)v\frac{dH^2}{dx}$$

$$= (k_1 - k_2)vH\frac{dH}{dx} \quad \dots\dots\dots\dots\dots\dots \quad (1)$$

We are concerned only with the NET force on the specimen and if the surrounding medium were a vacuum, this reduces to Force $= k_1 vH\dfrac{dH}{dx} = \chi_1 mH\dfrac{dH}{dx}$. This expression is basic to the theory of common methods for determining the susceptibility k of the material. The behaviour of diamagnetic and paramagnetic substances in a non-uniform magnetic field can be understood by examining equation (1). Assuming that $k_2 \ll k_1$, then for a *diamagnetic* substance the force F on the sample is negative in the direction of increasing H—i.e. the sample tends to move from a stronger to a weaker part of the field. The converse is true for *paramagnetic* substances.

Diamagnetism.

Diamagnetism is a property of all atoms whether they possess an overall paramagnetism or not. It arises from the tendency of all electrons in closed shells to orient their planes of rotation so as to suffer the minimum interaction with the imposed magnetic field. For a polyelectronic *atom* both classical mechanics and quantum mechanics lead to the expression $\chi_A = -\dfrac{Ne^2}{6mc^2}\Sigma_n \overline{r_n^2}$ for the atomic susceptibility. In this expression N is Avogadro's number, e the unit of electrostatic charge, c the velocity of light and m the mass of the electron.

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* E.g., a cylinder of the material suspended with the top end in a negligible field and the bottom in a powerful field H.

The expression $\sum\limits_{n}\overline{r^2}$ represents the sum of the squares of the projections of the orbits for all the electrons on a plane. On substituting for the constants we obtain the expression $\chi_A = -2\cdot832\times10^{10}\times\sum\limits_{n}\overline{r_n^2}$.

It is clear that for an atom, diagmagnetic susceptibility should be virtually independent of temperature—which is found to be true in practice—and should be very sensitive to factors which affect the value of $\overline{r^2}$. For example, the χ_A for argon (-19×10^{-6}) is numerically larger than for the iso-electronic K^+ ion (-14×10^{-6}) because the charge on the potassium ion contracts the area of the electronic orbits. It is mainly upon this sensitivity of $\overline{r^2}$ to environment that the use of diamagnetic measurements for stereochemical purposes depends.

TABLE 2.
Pascal's Diamagnetic Constants (Based on $\chi_{H_2O}=-0\cdot72\times10^{-6}$).

Elements.	$\chi_A\times10^{-6}$.	Constitutive Corrections.	—
H	$-2\cdot93$	Double bond —C=C—	$+5\cdot47$
C	$-6\cdot00$	Triple bond —C≡C—	$+0\cdot77$
N open chain	$-5\cdot57$	C in benzene ring	$-0\cdot24$
closed chain	$-4\cdot61$	C atoms common to two benzene	
mono-amides	$-1\cdot54$	rings as in naphthalene ..	$-3\cdot07$
diamides and imides	$-2\cdot11$	Double bond in —N=N— ..	$+1\cdot82$
O alcohols, ethers	$-4\cdot61$	Cl on saturated aliphatic C ..	$+3\cdot07$
ketonic	$+1\cdot73$	Br ,, ,, ,, ..	$+4\cdot08$
double bonded in carboxyl ..	$-3\cdot36$	I ,, ,, ,, ..	$+4\cdot08$
F	$-11\cdot5$	C=C—C=C	$+10\cdot6$
Br	$-30\cdot64$	—C—C	$+3\cdot1$
I	$-44\cdot64$	—C—Br	$+4\cdot1$
S	$-14\cdot98$	—C=N—R	$+8\cdot2$
Se	$-23\cdot04$	Tertiary C, α, γ, δ or ε to O atom	$-1\cdot29$
Te	$-37\cdot34$		
P (tervalent)	$-26\cdot30$	Quaternary C, α, γ, δ or ε to O atom	$-1\cdot54$
As ,, ...	$-43\cdot0$	Tertiary or quaternary C, β to O	
		atom	$-0\cdot48$
Sb ,, ...	$-74\cdot40$		
Bi ,, ...	$-182\cdot0$		
Si	$-20\cdot0$		

Note.—The values quoted are chiefly from Bhatnagur and Mathur (1935). For the heavier elements the decimal points are illusory except when one is comparing compounds of a very similar kind.

For a *molecule* having no unpaired electrons, a second term is involved in the total susceptibility. This is the contribution caused by Van Vleck (1932) or temperature independent paramagnetism which we shall represent by $\chi_{V.V.}$. It arises from the possibility of transitions from the diamagnetic ground state to an excited state, the energy difference between which is large compared with kT. Thus for a polyatomic molecule the experimental figure χ_M should equal $\sum\chi_A+\chi_{V.V.}$. In practice the calculation of atom and molecular diamagnetic susceptibilities is very difficult and agreement with experiment is only approximate. One usually follows Pascal's approach and assigns to each atom a fixed diamagnetism (see Table 2) and attributes all deviations from the experimental value to a

series of constants called " constitutive corrections ", i.e. λ. Thus $\chi_M = \Sigma\chi_A + \lambda$. The term λ includes corrections for double bonds, position isomerism, presence of aromatic rings, etc.

The values quoted above are for covalent molecules. For *ions* the corrections vary depending on the charge. A positive charge decreases χ_A in comparison with Pascal's constant, whereas a negative charge increases χ_A.

The simplest application of diamagnetic measurements for structural purposes is in connection with *keto-enol* isomerism. Thus, if acetone exists in the keto form, CH_3-C-CH_3, the calculated χ_M is $-33 \cdot 58 \times 10^{-6}$. For the *enol*

$$\underset{O}{\overset{||}{}}$$

form, $CH_3-C=CH_2$, χ_A is $-34 \cdot 9 \times 10^{-6}$. The experimental value of $-33 \cdot 64 \times 10^{-6}$

$$\underset{OH}{\overset{|}{}}$$

supports the accepted ketonic structure. Diamagnetic measurements have been used fairly extensively in studies of keto-enol isomerism but the value of the results both here and in other similar problems is limited by the following : (i) The need for very pure compounds. Traces of paramagnetic compounds are particularly serious. (ii) The need for very accurate measurements. (iii) The need for measurements on suitable similar model compounds for the determination of constitutive corrections. Attempts have been made to improve on Pascal's empirical constants. Gray and Cruickshank (1935) have endeavoured to allow for different resonance hybrids by utilizing bond dipole moments and other physical data. However, their premises are in certain cases no longer tenable and the theory is no longer generally accepted. More recently French (1955) has critically examined the Gray and Cruickshank theory.

The large change in diamagnetic susceptibility when a double bond disappears, e.g. as in the polymerization of an unsaturated compound, is noteworthy and can be used to follow the reaction. However, no information as to stereochemistry is provided.

There is no doubt that studies of diamagnetism will lead eventually to useful information on stereochemistry but until a lot more work, both experimental and theoretical, has been done it is not possible to use diamagnetic measurements with any confidence as diagnostic of stereochemistry.

Paramagnetism.

Paramagnetism is found in those substances the atoms or molecules of which have a permanent magnetic moment. When the molecules are free to orient themselves, ideally in the gas phase but in practice also in solution and even in the solid state if magnetically dilute,* they are subject to two opposing effects.

These are (i) the magnetic field H which tends to align the molecular magnets in the same direction as that of the field, and (ii) the thermal agitation (kT effect) which tends to randomize the directions of the molecular magnets. Clearly, as T decreases, the effect of the applied field becomes relatively stronger. It can be shown that ideally the susceptibility is given by the expression $\chi_P^{\dagger} = \dfrac{N^2\mu^2}{3RT}$ where N is Avogadro's number, μ the magnetic moment, R the universal gas constant, and T the absolute temperature. In practice one

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* A magnetically dilute substance is one in which the *ratio* of diamagnetic to paramagnetic atoms is large ; e.g. $[Ni(NH_3)_6]I_2$ is magnetically dilute (ratio 26 : 1) whereas FeO is magnetically concentrated (ratio 1 : 1).

† χ_P might be called the " orientation susceptibility ", arising from the interaction of permanent magnetic dipoles with an applied magnetic field.

measures χ leading to χ_M which is the sum of $\chi_P + \chi_{V \cdot V \cdot} + \chi_D$, where χ_D is the sum of the diamagnetic contribution to the susceptibility. As one usually does not know the value of $\chi_{V \cdot V \cdot}$ it is customary to use in place of χ_P in the above expression the " corrected molar susceptibility χ_M^1 which equals $\chi_M + \chi_D$. The value of the magnetic moment obtained using χ_M^1 is called the effective magnetic moment μ_{eff}. Substituting for the fundamental constants in the above expression one obtains the relationship $\mu_{\text{eff}} = 2 \cdot 84 \sqrt{\chi_M^1 \times T}$. If the susceptibility χ_P is proportional to $\dfrac{1}{T}$ as required by the expression $\chi_P = \dfrac{N^2 \mu^2}{3RT}$ the susceptibility follows the Curie Law and μ_{eff} is independent of T. More commonly $\chi_P \propto \dfrac{1}{T + \theta}$ where θ is a constant over a greater or lesser range of temperature. A substance which follows this relationship is said to follow the Curie-Weiss Law ; if this law is followed, μ_{eff} is independent of temperature only if one uses $(T + \theta)$ instead of T in the expression $\mu_{\text{eff}} = 2 \cdot 84 \sqrt{\chi_M^1 \times T}$.

The origin of paramagnetism (ignoring nuclear spin from which the contribution is negligible) is to be found in the fact that extra nuclear electrons possess both spin and orbital angular momenta. The former can be visualized classically as arising from the electron " spinning " on its own axis and the latter from its angular velocity in moving around the nucleus. The idea of electrons travelling in planetary orbits around the nucleus is no longer tenable in the light of modern quantum mechanics but the concept of orbital angular momentum is mathematically useful even if pictorially incorrect. For a single unpaired electron the spin angular momentum is given by $\dfrac{1}{2} \cdot \dfrac{h}{2\pi}$. For n unpaired electrons with parallel spins the total spin angular momentum (S) is given by $\dfrac{n}{2} \cdot \dfrac{h}{2\pi}$. Similarly, the unit of angular momentum is $\dfrac{h}{2\pi}$; the total angular momentum for any particular electron is given by $l \cdot \dfrac{h}{2\pi}$ where l is the subsidiary quantum number. For an atom containing n unpaired electrons the total spin angular momentum is given by $S \cdot \dfrac{h}{2\pi}$ where $S = \dfrac{n}{2}$. Similarly, the total orbital angular momentum is given by $L \cdot \dfrac{h}{2\pi}$, L being the vector sum of the individual subsidiary quantum numbers l_1, l_2, l_3, etc. We now must see how L and S combine to give a resultant total angular momentum. This is given by the inner quantum number J. The rules governing the combination of L and S to give J are quoted in the footnote.* Finally we are led to the relationship between angular momentum and magnetic moment. It can be shown classically that a single electron of subsidiary quantum number l revolving around a nucleus an angular momentum $l \cdot \dfrac{h}{2\pi}$; in quantum mechanics this becomes $\sqrt{l(l+1)} \cdot \dfrac{h}{2\pi}$ and this in turn gives a magnetic moment of

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* Hund's Rules are :

(1) Of the possible terms allowed by the Pauli principle, that with the maximum multiplicity lies lowest. (Multiplicity $= 2S + 1$).

(2) If there are several ways in which L and S may be coupled so as to maintain the maximum multiplicity, then the lowest lying term is that with the maximum value of L.

(3) If a sub-group of electrons is *less* than half full, the multiplets are " normal ", i.e. smallest J has lowest energy. For shells more than half full the *largest* J lies lowest.

$\sqrt{l(l+1)}$. $\dfrac{eh}{4\pi mc}$ C.G.S. units. For convenience $\dfrac{eh}{4\pi mc}$ is called 1 Bohr Magneton ; it equals $9\cdot18\times10^{-21}$ C.G.S. units. For reasons which need not concern us here the unit of spin angular momentum $\frac{1}{2}\cdot\dfrac{h}{2\pi}$ gives rise to the same magnetic moment as the unit of angular momentum $\left(\dfrac{h}{2\pi}\right)$ which is twice as large.

We shall concern ourselves in the discussion which follows solely with compounds of elements of the first transition series (scandium to zinc). For this purpose we need to consider five types of magnetic moment. These are :

(1) *Rare Earth Type.* This is the ideal magnetic behaviour and arises (*a*) when the unpaired electrons responsible for paramagnetism are well shielded from external forces and (*b*) when the ground state of the atom is separated from the next higher excited state by an energy difference ($h\nu$) large compared with kT. The magnetic moment is given by the equation $\mu=g\sqrt{J(J+1)}$. g is the Landé Splitting Factor given by the expression

$$1+\frac{J(J+1)+S(S+1)-L(L+1)}{2J(J+1)}.$$

For substances showing this type of magnetic behaviour μ is independent of the stereochemical environment and the magnetic dilution. Magnetic moments of this type are not shown by the iron group elements but it is the ideal behaviour from which deviations occur to a greater or lesser extent.

(2) *Small Multiplet Separation.* When the energy separation between successive J values ($h\nu$) is very small compared with kT it is found that L and S no longer couple together to give a resultant J, but each reacts separately with an external field. Under these circumstances the calculated value of μ is given by $\sqrt{4S(S+1)+L(L+1)}$. This is the opposite extreme to case (1) and is the limit towards which μ approximates as $h\nu_{(J_0-J_1)}$ approaches zero.

(3) *Intermediate Multiplet Separation,* i.e. $h\nu_{(J_0-J_1)}$ comparable with kT. When this situation arises, there is a distribution of the molecules over the various J values decided by the Boltzmann equation. Examples include NO, Sm^{+++} and Eu^{+++}.

(4) *Iron Group Type.* It has been known for a long time that the magnetic moments of the irons of the elements of the first transition series ($Ti\rightarrow Cu$) agree neither with the large multiplet separation formula $\mu=g\sqrt{J(J+1)}$ nor the very small multiplet separation formula $\mu=\sqrt{4S(S+1)+L(L+1)}$.* Agreement between theory and experiment is best given by the simple expression $\mu=\sqrt{4S(S+1)}$, at least for the first half of the series, the whole of the orbital contribution $L(L+1)$ being ignored. This is shown later in Table 5. However, the quenching of this orbital contribution is often not complete and this deviation from the " spin-only " formula $\mu=\sqrt{4S(S+1)}$ can be used to assist in determining stereochemistry in ideal cases as discussed on page 21. The calculated values of μ for 1 to 5 unpaired electrons are given in Table 3.

(5) *Covalent Bond Type.* Finally it is often found that the moments of certain complexes are much less than those predicted by the Hund formula.

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* Actually, this formula does agree with experimental μ_{eff} values for certain octahedral Co(II) complexes. See Table IV.

Thus, whereas the Fe^{+++} ion has the expected 5 unpaired electrons in K_3FeF_6, in $K_3Fe(CN)_6$ the moment of $2\cdot34$ B.M. indicates only one unpaired electron. This " electron pairing " occurs in many complexes of the first transition series with ligands of low electronegativity and is the norm for all complexes of the second and third transition series irrespective of the attached ligands.

TABLE 3.
Magnetic Moments for Spin Only.

Number of Unpaired Electrons.	Magnetic Moment in Bohr Magnetons.
1	$1\cdot73$
2	$2\cdot83$
3	$3\cdot88$
4	$4\cdot90$
5	$5\cdot92$

Applications of Paramagnetic Susceptibilities.

In inorganic chemistry these measurements are useful for three main purposes. Provided that the number of *unpaired electrons* can be deduced from the magnetic moment, it is possible to infer from the former, (i) the *valency*, (ii) the *bond type*, and (iii) the *stereochemistry* of the metal atom. Use can be made of the size of the *orbital contribution* to the *moment*, in the case of first transition elements, to obtain information concerning the stereochemistry of the metal atom. The discussion which follows will be concerned solely with the elements of the first transition series.

(1) *Valency Problems.* This is the best known application of magnetic susceptibility measurements. Having inferred the number of unpaired electrons, we can then distinguish different possible valency states provided that they contain different numbers of unpaired electrons. The decision is specially easy with first transition elements because Hund's rules are obeyed for the simple ions. Thus Fe^{+++} contains 5 unpaired electrons, whilst Fe^{++} has only four (cf. Table 3) ; these correspond to moments of $5\cdot9$ and $4\cdot9$ B.M. respectively. Similarly Cu(I) and Cu(II) may be distinguished because the former is diamagnetic. When electron pairing occurs, valency states may be distinguished if one involves diamagnetism and the other contains one unpaired electron. These conditions obtain for those compounds of the first transition series for which maximum electron pairing occurs, e.g. $K_3Fe(CN_6)$ and $K_3Fe(CN)_6$, and for practically all of the small number of paramagnetic compounds of the second and third transition series, e.g. Pd(III) in PdF_3 which contains one and not three unpaired electrons ; both Pd(II) and Pd(IV) are diamagnetic. A few compounds fall in between these two extremes, e.g. Ru(IV) and certain Cr(II) complexes which contain two unpaired electrons rather than four or nil. The reason for this will be discussed under bond types. The magnetic criterion of valency is so reliable today that unless paramagnetism is observed in a compound for which the valency state should have an odd number of electrons, then the ascribed valency must be regarded with some suspicion. The valency of an element when spin coupling between two like atoms occurs is often debatable, e.g. as in the Hg_2^{++} ion, $Fe_2(CO)_9$, $Co_2(CO)_8$.

(2) *Type of Bond in Metal Complexes.* Magnetic moments can be used to distinguish between two types of binding in metal complexes, particularly those of the first transition series. This division has long been recognized on chemical

grounds alone ; a freely dissociable Co(II) ammine is known as a " normal-komplexe ", while the more robust Co(III) ammines, which do not undergo reversible thermal dissociation, are examples of " durchdringungskomplexe " (penetration complexes). In the case of Fe(III), the first class (e.g. ferric trisacetylacetone) have moments of $5 \cdot 9$ B.M., indicating five unpaired $3d$ electrons ; the second class (e.g. potassium ferricyanide) have moments of $2 \cdot 3$–$2 \cdot 4$ B.M., a little greater than the spin-only value for one unpaired electron. Two main theories, the Crystalline Field Theory and the Pauling Theory, have been advanced to explain this difference in moment ; the Molecular Orbital approach has received less attention. Pauling (1945) suggested that the bonds in the first class are essentially electrostatic (" ionic bonds "), whilst in the latter, $3d$ orbitals are involved in the binding ($3d^2 4s 4p^3$ " covalent bonds "). The two $3d$ orbitals required for bond formation are supposed to be made available by electron pairing, leaving only one unpaired $3d$ electron. In the first case the five $3d$ electrons are unaffected by complex formation. Van Vleck (1935) showed that strong crystalline forces* could also bring about electron pairing ; in the ferricyanides, for example, strong forces were believed to upset the Russell-Saunders coupling, giving the minimum number of unpaired spins. If the attached ligands are not held strongly to the Fe atom, the spin multiplicity is unaffected. Pauling pointed out that on Van Vleck's theory one might expect spin pairing in K_3FeF_6 because strong electrical fields should be present. Van Vleck agreed that in this instance, at least, the Pauling and the molecular-orbital approach are both more satisfactory on empirical grounds. Orgel (1952), after re-examining the relation between the Pauling and the Van Vleck theory, has shown that these are really only two different ways of approaching the problem ; the qualitative similarity is demonstrated, and it is pointed out that both theories should in all cases lead to the same conclusion. In comparing the effect of a CN^- as against a F^- ion, the polarizability of the ion, rather than the intensity of the field at its surface, is of paramount importance in determining the resultant crystalline field. This weakens Pauling's argument against Van Vleck's picture. It is satisfactory to know that there is really no conflict between these two theories because Pauling's approach is easier for most purposes and has found general acceptance. It will be used widely in the following discussion of stereochemistry. Recent work has done much to remove certain objections (based as much as anything on terminology) to Pauling's original theory. It had been pointed out, e.g. by Sugden (1943), that the physical properties of compounds like ferric trisacetylacetone were incompatible with the view that the bonds were " ionic ". Later, Pauling emphasized that the term " ionic " was not to be taken too literally, and envisaged a type of covalent binding in the above compound in which four $4s 4p^3$ bonds resonated among six positions in an ionic octahedral complex. Because they were considered to be too unstable for bond formation, Pauling originally rejected Huggins's (1937) suggestion that $4d$ orbitals might be used in combinations such as $4s 4p^3 4d^2$ for octahedral binding. Huggins's proposals have been re-examined by several workers. Taube (1952) refers to the two types of complex as " inner d orbital type " ($3d^2 4s 4p^3$ bonds) and " outer d orbital type " ($4s 4p^3 4d^2$ bonds). A similar proposal has been put forward by Burstall and Nyholm (1952) in discussing the magnetic behaviour of dipyridyl and ditertiary arsine complexes of the transition metals. Overlap calculations by Craig *et alii* (1954) provide theoretical support for the view that $4d$ orbitals may be used for σ-bond formation in the so-called " ionic " complexes. The fact that $4d$ orbitals are well elongated means that good overlap occurs at relatively greater distances from the metal atom than occurs when $3d$ orbitals are used. Hence the electron cloud of the

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* Electrical fields which arise from the regular arrangement of charged ligands around the paramagnetic atom.

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bonding electron pair lies further over towards the ligand, i.e. the bond is more polar. Thus the difference between the terms "ionic" or "higher level covalent bonds" is not as great as it seems at first sight. However, the possibility of exchange owing to the size of the overlap integral is explicit in the latter but not in the former.

The above ideas enable one to understand why some atoms are more effective than others in causing electron pairing. The more electronegative atoms (F, O) favour "higher level covalent binding" because they tend to concentrate the bonding electron pair closer to the ligand, resulting in the use of $4d$ orbitals. On the other hand, the groups of low electronegativity (e.g. P, As) utilize more readily the $3d$ orbitals, and hence give rise to "lower level covalent bonds". In the binding of groups of low electronegativity such as the CN, NO_2 and AsR_3 ligands, it is probable that double (π) binding makes a significant contribution to the strength of the bond. These π bonds could increase the bond strength for three reasons : they increase the number of bonds between the metal and ligand ; they provide a mechanism whereby the improbably high negative charge on the metal atom may be delocalized ; finally, partly as an outcome of the latter, they provide a method for strengthening the σ bond. For a more detailed discussion the reader is referred to Nyholm (1954).

TABLE 4.

Electronic Arrangement, Magnetic Moments and Stereochemistry of Cobaltous Compounds.

Complex.	Electronic Arrangement.			Unpaired Electrons.	μ (B.M.) Observed.
	$3d$	$4s$	$4p$		
(i) Co (Metal)	↑↓ ↑↓ ↓ ↓ ↓	↑↓	□ □ □		
(ii) Co²⁺ (free ion)	↑↓ ↑↓ ↓ ↓ ↓	□	□ □ □	3	4·8–5·2
(iii) Co^{II} four tetrahedral $4s4p^3$ bonds	↑↓ ↑↓ ↓ ↓ ↓	↑↓	↑↓ ↑↓ ↑↓	3	4·3–4·8
(iv) Co^{II} four square planar $3d4s4p^2$ bonds	↑↓ ↑↓ ↑↓ ↓ ↑↓	↑↓	↑↓ ↑↓	1	2·1–2·9
(v) Co^{II} six octahedral $3d^24s4p^3$ bonds	↑↓ ↑↓ ↑↓ ↑↓ ↑↓	↑↓	↑↓ ↑↓ ↑↓	1	1·7–1·9

(In row (v) the $5s$ orbital contains ↓.)

When it is not possible to free $3d$ orbitals for bond formation by pairing $3d$ electrons, Pauling suggests that "promotion" of electrons to higher levels *above* the bonding orbitals occurs. Such a promotion is postulated in octahedral covalent Co(II) complexes for which the binding is apparently $3d^24s4p^3$; this is shown in Table 4. It can be seen that no such promotion is necessary for square complexes. In the octahedral complex the promoted electron is assumed to occupy an exposed $5s$ orbital and hence should be lost easily by oxidation to yield a diamagnetic Co(III) complex. This corollary has proved both a strength and a weakness of the theory. The chemical behaviour of some complexes, e.g. the $[Co(NO_2)_6]^{4-}$ ion, supports the assumption, but in certain other cases where promotion has been assumed the evidence is unconvincing, e.g. Cu(II) (see below).

(3) *Stereochemistry.* Magnetic moments can be used in ideal cases to determine the stereochemistry of certain transition metal complexes provided that the arrangement of the ligands is dependent upon the use of covalent bonding orbitals of the central metal atom. The relationship between shape and bonding orbitals is given in Table 5, arrived at by Kimball (1940) using group theory. As discussed under bond type, once one has inferred the bonding orbitals the stereochemistry is known.

TABLE 5.
Stable Bond Arrangements and Stereochemistry.

Coordination Number.	Arrangement.	Combination of Orbitals.
2	Linear .. .. .. Angular	$sp, dp.$ $p^2, ds, d^2.$
3	Trigonal plane .. .. Unsymmetrical plane .. Trigonal pyramid ..	$sp^2, dp^2, d^2s, d^3.$ $dsp.$ $p^3, d^2p.$
4	Tetrahedral .. .. Tetragonal plane .. Irregular tetrahedron .. Tetragonal pyramid ..	$sp^3, d^3s.$ $dsp^2, d^2p^2.$ $d^2sp, dp^3, d^3p.$ $d^4.$
5*	Bipyramid .. .. Tetragonal pyramid .. Pentagonal plane .. Pentagonal pyramid ..	$dsp^3, d^3sp.$ $d^2sp^2, d^4s, d^2p^3, d^4p.$ $d^3p^2.$ $d^5.$
6	Octahedron .. .. Trigonal prism .. Trigonal antiprism .. Mixed	$d^2sp^3.$ $d^4sp, d^5p.$ $d^3p^3.$ $d^3sp^2, d^5s, d^4p^2.$
7†	$[ZrF_7]^{3-}$ structure .. $[TaF_7]^{2-}$ structure ..	$d^3sp^3, d^5sp.$ $d^4sp^2, d^4p^3, d^5p^2.$
8	Dodecahedron .. .. Antiprism .. .. Face-centred prism ..	$d^4sp^3.$ $d^5p^3.$ $d^5sp^2.$

* In addition to the bipyramid using $(ns)(np^3)nd$ orbitals (where n is the principal quantum number), Daudel and Bucher (1945) have shown that if the d orbital is a quantum level one less than that of the s and p, i.e. $(n-1)d$, ns, $(np)^3$ orbitals, a square pyramid is obtained. This conclusion also follows from the group theory approach (Craig, 1953).

† The pentagonal bipyramid (IF_7) was not discussed by Kimball. See also Duffey (1950).

The basic principles of the Pauling theory relating stereochemistry in the first transition series with magnetic moments are :

(1) For most purposes the number of unpaired electrons in an atom may be computed from the " spin only " formula,* i.e. magnetic moment $\mu = \sqrt{n(n+2)}$ Bohr magnetons (B.M.) where n = number of unpaired electrons.

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* The size of the orbital contribution rarely gives rise to any doubt as to the *number* of unpaired electrons.

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(2) When the magnetic moment of a complex is essentially the same as that of the free ion* (i.e. no spin coupling occurs) the bonds do not involve $3d$ orbitals.   In the Pauling terminology the binding is " ionic ".

(3) Spin coupling with a reduction of either two or four in the number of unpaired electrons indicates that $3d$ orbitals are being used for (" covalent ") bond formation.   This necessitates the transfer of unpaired electron(s) originally occupying the $3d$ orbital(s) now used for bond formation.   Usually these displaced electron(s) pair off with other unpaired non-bonding $3d$ electrons.

(4) If no vacant $3d$ orbital(s) are available to accommodate the displaced electron(s) referred to in (3), then electron(s) may be promoted to vacant orbital(s) above those used for bond formation.

(5) The orbitals used for σ bond formation are usually those immediately above those occupied by non-bonding electrons provided that these are a permissible combination for bond formation.   This assumption is unreliable in certain cases where no electron pairing occurs (cf. square Cu^{II}).

These principles are illustrated in Table 4 showing the electronic configuration of various complexes of bivalent cobalt.   In (iii) no electron pairing occurs ; in (v) two $3d$ orbitals are used for covalent bond formation, one electron being promoted.

However, there are certain cases where the conclusions are open to doubt. This is specially so when no electron pairing occurs.   Thus in a Cu(II) complex there is one unpaired electron, presumably in a $3d$ orbital.   The next most readily available bond orbitals are $4s4p^3$ leading one to expect a tetrahedral arrangement in four-covalent complexes.   Since all Cu(II) complexes whose structures have been determined are square planar, Pauling assumed that the bonds are $3d4s4p^2$, one unpaired electron being promoted to a $4p$ orbital, but there are serious objections to this hypothesis.   First, promotion of the electron to a $4p$ orbital should result in facile oxidation of square Cu(II) complexes to the tervalent state—which is not observed in practice.   Also, theoretical work leads to the conclusion that fairly electronegative groups like H_2O and NH_3 (which do give square Cu(II) complexes) are more likely to use $4d$ than $3d$ bond orbitals. In the case of Ni(II), for example, where the diamagnetism is diagnostic of the square arrangement, groups of *low* electronegativity are required to form $3d4s4p^2$ square bonds.   Huggins's suggestion that the bonding orbitals are $4s4p^24d$ without electron promotion has been re-examined by Ray and Sen, who obtained the susceptibilities of a large number of Cu(II) complexes at various temperatures and calculated μ on the Curie-Weiss law.   The moments fell roughly into two classes, some between $1 \cdot 8$ and $1 \cdot 9$ B.M. and others between $1 \cdot 9$ and $2 \cdot 2$ B.M., but the division was by no means sharp.   They suggested that the first group involved $3d4s4p^2$ bonds with electron promotion, and the second are considered to be either $4s4p^3$ tetrahedral or $4s4p^24d$ square planar.   The smaller moment of compounds in the first group is attributed to the greater quenching effect of the crystalline field upon the exposed electron ; however, there is no evidence to support the claim that electron promotion really occurs.   Finally, the existence of octahedral Cu(II) complexes, e.g. $[Cu(NH_3)_6]X_2$, is more easily explained by the formation of $4s4p^34d^2$ bonds, without electron promotion, than by the improbable $3d^24s4p^3$ combination requiring the promotion of three electrons. The former combination follows logically from a square $4s4p^24d$ complex by completing the octahedron.   The hypothesis of promotion of electrons is now

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* Provided that the free ion contains *more* than three $3d$ electrons ; this proviso is necessary because magnetic moments do not distinguish between $4s4p^34d^2$ and $3d^24s4p^3$ octahedral binding when three $3d$ electrons or less are present, e.g. Cr^{III}.

regarded with more caution than formerly. Generally speaking, one should be reluctant to postulate promotion unless supporting evidence is available. This, for example, is available for octahedral Co(II) complexes ; the unpaired electron is believed to occupy a $5s$ orbital. The fact that the orbital contribution is negligible, as it should be for an s electron, lends support to the hypothesis.

Orbital Contribution to Magnetic Moments and Stereochemistry.

For many paramagnetic ions of the first transition series, the contribution to the magnetic moment arising from orbital motion (i.e. the excess over and above the spin only value) is a variable quantity. The size of this orbital contribution is affected in a fairly definite manner by the stereochemical arrangement of the attached groups. It is natural therefore to attempt to use this orbital contribution as yet another tool in the elucidation of stereochemistry. Two types of complex need consideration : (1) those complexes in which the *number* of the unpaired electrons in the complex is the same as in the free ion, e.g. $[Co(NH_3)_6]Cl_2$ (the so-called " ionic complexes ") ; (2) those complexes in which electron pairing occurs and Hund's rules break down, e.g. $K_3Fe(CN)_6$ (the so-called " covalent complexes "). We shall discuss each in turn.

(1) Orbital Contribution in Ionic Complexes.

It was pointed out earlier (p. 15) that the magnetic moments of the metal ions of the first transition series as a rule do not agree with the large $hv_{(J_o \rightarrow J_1)}$ interval formula ($\mu_{eff} = g\sqrt{J(J+1)}$), with the small interval formula ($\mu_{eff} = \sqrt{4S(S+1) + L(L+1)}$), nor with the more complicated formula which uses the actual multiplet separation intervals. In general the moments are

TABLE 6.
Magnetic Moments of First Transition Series.

Metal ion	Ti++	V++	Cr++	Mn++	Fe++	Co++	Ni++	Cu++
Spectroscopic state	F	F	D	S	D	F	F	D
μ_{eff} calculated $\sqrt{4S(S+1)}$	2·83	3·88	4·90	5·92	4·90	3·88	2·83	1·73
μ_{eff} observed	—	3·8–3·9	4·8–4·9	5·2–6·0	5·1–5·7	4·3–5·6	2·8–3·5	1·8–2·2*
Metal ion	Ti+++	V+++	Cr+++	Mn+++	Fe+++	Co+++	Ni+++	Cu+++
Spectroscopic state	D	F	F	D	S	D	F	F
μ_{eff} calculated $\sqrt{4S(S+1)}$	1·73	2·83	3·88	4·90	5·92	4·90	3·88	2·83
μ_{eff} observed	1·7–1·9	2·7–2·9	3·8–3·9	4·7–5·0	5·4–6·0	—	—	2·8

* Certain newly discovered five-covalent Cu++ complexes have moments up to 2·6 B.M.

accounted for most satisfactorily by assuming that the orbital angular momentum ($L(L+1)$) is largely or completely quenched leaving only the spin momentum operative. For bi- and tervalent ions agreement with the formula $\mu_{eff} = \sqrt{4S(S+1)}$ is very good for the first half of the series (i.e. Ti+++ to Mn++ or Fe+++) but the deviation is much more marked for Fe++ and for the bi and tervalent states of the metals Co, Ni and Cu. This is illustrated by Table 6.

In order to understand how the stereochemical arrangement of the ligands attached to the metal ion affect the size of the orbital contribution, it is first necessary for us to examine the way in which the energy levels of an ion are

affected by the crystalline electrical field produced by the charged groups surrounding the metal ion. The electrical field may be considered to arise mainly from the groups directly attached to, or in immediate proximity with, the metal ion, but longer range forces also appear to have a definite but smaller effect. We shall confine this discussion to the first of these two. Reference to Table 6 shows that for the ions of the first transition series the spectroscopic ground states are S, D or F states.* In the first of these the orbital angular momentum (L) is zero, and hence there is no orbital contribution to the moment. For ions in this S state the value of μ_{eff} is given by the spin only formula irrespective of the arrangement of the ligand around the metal ion ; small deviations which do occur result in moments *less* than the spin only value. These involve effects† which are of no diagnostic value so far as inorganic stereochemistry is concerned. However, for both D and F states the position is quite different. In the following discussion we shall confine our attention mainly to Fe, Co, Ni and Cu—particularly when bivalent.

Let us consider first of all the simpler case, that of an ion in an F state, taking as our example the Co^{++} ion. The arrangement of electrically charged particles about a metal ion, e.g. the four Cl$^-$ ions in the tetrahedral $(CoCl_4)^=$ complex ion, gives rise to an electrical field about the central metal ion. This electrical field has two main effects. Firstly, the coupling of the L and S vectors is largely broken up, so that the ion is no longer specified by a particular J value. Secondly, the $2L+1$ sublevels associated with the particular L value, which are degenerate in the normal ion, with no electrical field superimposed, are usually split apart with separations between levels which have important effects upon the contribution which the orbital momentum makes to the magnetic moment. It should be recalled that for an ion with narrow multiplet separation, i.e. $h\nu_{(J_0-J_1)} \ll kT$, having no electrical field operating, the effect of an external magnetic field is to react separately with S and L lifting the degeneracies of these into their $2S+1$ and $2L+1$ sublevels. The distribution over the $2L+1$ levels is what gives rise to the large orbital contribution to the magnetic moment in the formula $\mu = \sqrt{4S(S+1)+L(L+1)}$. Now, if the electrical crystalline field should split the L value so that the separation between any two sublevels is large compared with kT then only the lowest (or lower) levels will be populated. Furthermore, should this lowest level be only a singlet, then the orbital contribution to the magnetic moment should be very small.

Bethe (1929, 1930) examined by group theory methods the effect of various kinds of electrical crystalline fields on F and D states for transition metal ions. He found that if an ion is in an F state, e.g. Co^{++} when at the centre of a cubic‡ electrical crystalline field, such as is produced when the Co^{++} ion is at the centre of a *perfect* octahedron of H_2O molecules, the single energy level is split into three new levels, the separation between successive levels being about 10^4 cm^{-1} (kT at 20° C. is approximately 204 cm^{-1}, small compared with 10^4 cm^{-1}).

Usually small departures from cubic symmetry occur owing to slight distortion of the octahedron. This may be regarded as equivalent to imposing on the field a small component of lower symmetry, e.g. tetragonal or rhombic. §

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* The spectroscopic terms S, P, D and F refer to the value of L for the ion. The values are respectively 0, 1, 2 and 3.

† Both metal-metal interaction (as in the Hg$_2$$^{++}$ ion) and antiferromagnetism can cause reduction in the moment of S state ions.

‡ Cubic field—three axes at right angles, all equal ; tetragonal field—three axes at right angles, two equal ; rhombic field—three axes at right angles, all unequal ; trigonal field—two equal axes at 120° (X and Y) *not* equal to a third perpendicular to these two.

§ The most usual distortion is for two co-linear metal H_2O bonds to be slightly longer than the other four bonds in the plane at right angles to this axis.

This rhombic component causes a further splitting of two adjacent energy levels into triplets; the energy separation between the sublevels of the triplet is of the order kT. This gives seven levels in all for an F state. An example of this kind of separation is given by $[Co(H_2O)_6]^{++}$ ion, shown in Table 7A. This is known as a " Stark Pattern ".

In this case the triplet level is lowest and the singlet is highest. This means that the populations of all three levels of the lowest lying triplet are appreciable, whereas the intermediate triplet and upper singlet state have a negligible population. The distribution over the three sublevels of the lowest lying triplet is according to the usual Boltzmann temperature dependent function.

Van Vleck (1932a), Penney and Schlapp (1932, 1933), Bethe (1929, 1930), Gorter (1932) and others have attempted to explain quantitatively the splitting of the original single F level using expressions for the potential of the electrical crystalline field such as $V = Ax^2 + By^2 - (A+B)z^2 + D(x^4+y^4+z^4)$. A, B and D are constants which depend upon the charges on the ligands, and their arrangement about the central metal ion. Usually the more simple expression $V = A(x^2+y^2-2z^2) + D(x^4+y^4+z^4)$ suffices. This expression represents a field which is symmetrical about the z axis; the effects of more distant atoms and powers other than those shown are ignored. The term involving the fourth power of x, y and z represents the field of cubic symmetry which is responsible for the initial separation of an F state into three levels ($\sim 10^4$ cm. apart). For the first transition series the constants A and B are of the order of 0 to 400 cm^{-1}, whilst D is positive and lies somewhere between 1000 and 1500 cm^{-1}. If one is dealing with an arrangement of negative charges about a metal ion it can be shown that D changes in sign in passing from the cubic field arising from six octahedral ligands to the cubic field due to four tetrahedral ligands. This change of sign results in an " Inversion of the Stark Pattern "; this is shown in Table 7B. The shape of the Stark pattern is also affected by the number x of d electrons; thus, if we consider the Ni^{++} ion instead of the Co^{++} ion the situation is exactly reversed, 7A arising from tetrahedral Ni^{++} and 7B arising from octahedral Ni^{++}. The patterns expected for the various bi- and tervalent first transition ions in a cubic field with a rhombic component are summarized in Table 8.

For an ion in a D state the cubic crystalline field splits the orbital level into two levels, the separation between which is large, cf. with kT. These two levels are in turn split by a small rhombic component into a triplet and a doublet. Where the triplet lies lowest, as for example with the Fe^{++} ion (see Table 8) when surrounded by six octahedrally co-ordinated negative charges, a large orbital contribution is expected. If the doublet is lowest, e.g. for Cu^{++} (Table 7B) in the same field a small orbital contribution can be expected because the doublet is said to be " non-magnetic ", for it behaves effectively as a singlet.

For the first half of the first transition series observed orbital contributions are negligible. For V^{++}, Cr^{+++}, Cr^{++} and Mn^{+++} this is in any case what we would expect for octahedral co-ordination. However, for octahedrally co-ordinated Ti^{++}, Ti^{+++} and V^{+++}, which have a triplet lying lowest, a large orbital contribution might be expected. This has never been observed, moments corresponding to the spin only value being obtained; Bose and Mitra (1952) attribute this complete orbital quenching to the small and positive values of the spin orbit coupling (Laporte, 1928) which, together with a rhombic field, result in the separation even of the orbitally degenerate cubic levels to widths large compared with kT.

For the ions of Fe, Co, Ni and Cu data are more interesting, most work having been done with Co^{++}. Octahedrally co-ordinated Fe^{++} and Co^{++} should have large orbital contributions which is in general true (see Table 5). On the

TABLE 7.

Stark Patterns for D and F State Ions.

7A.

Octahedral Co++
Cubic Field Constant D, Positive
Tetrahedral Ni++
Cubic Field Constant D, Negative

7B.

Tetrahedral Co++
Cubic Field Constant D, Negative
Octahedral Ni++
Cubic Field Constant D, Positive

7C.

Octahedral Fe++
Cubic Field Constant D, Positive
Tetrahedral Cu++
Cubic Field Constant D, Negative

7D.

Octahedral Cu++
Cubic Field Constant D, Positive
Tetrahedral Fe++
Cubic Field Constant D, Negative

TABLE 8.

Crystalline Field Effects on Ions of First Transition Series.

Ion	Ti+++	Ti++ V+++	V++ Cr+++	Cr++ Mn+++	Mn++ Fe+++	Fe++ Co+++	Co++ Ni+++	Ni++ Cu+++	Cu++
Spectroscopic ground state	$^2D_{3/2}$	$^3F_2$	$^4F_{3/2}$	$^5D_0$	$^6S_{5/2}$	$^5D_4$	$^4F_{9/2}$	$^3F_4$	$^2D_{5/2}$
Unpaired 3d electrons	1	2	3	4	5	4	3	2	1
L =	2	3	3	2	0	2	3	3	2
Lowest orbital level in cubic field component (+small rhombic component). Positive field constant, i.e. six octahedral charges	Triplet.	Triplet.	Singlet.	Non-magnetic doublet (equivalent to singlet.)	Singlet.	Triplet.	Triplet.	Singlet.	Non-magnetic doublet (equivalent to singlet).
Lowest orbital level in cubic field component (+small rhombic component). Negative field constant, i.e. four tetrahedral charges	Non-magnetic doublet (equivalent to singlet.)	Singlet.	Triplet.	Triplet.	Singlet.	Non-magnetic doublet (equivalent to singlet.)	Singlet.	Triplet.	Triplet.

other hand, for octahedrally co-ordinated Ni^{++} and Cu^{++} small orbital contributions are expected ; as shown by Table 6, this is, broadly speaking, what is found experimentally. For tetrahedrally co-ordinated Fe^{++} and Co^{++} a small orbital contribution would be predicted. Data are not available for Fe^{++} but for Co^{++} it is correct to say that the orbital contribution is much smaller than in the octahedral complexes. In theory tetrahedral Co^{++} might be expected to have a μ_{eff} close to $3 \cdot 88$ B.M. since the singlet is lowest ; Bose and Mitra (1952) propose that high frequency contributions are mainly responsible for the deviations from the spin only value in this case. They suggest that since kT becomes steadily larger as T increases the high frequency contribution should increase with T and, in fact, be proportional to T. This implies that there should be a fall towards the spin only value of $3 \cdot 88$ B.M. as T decreases. Data are scarce, but a definite decrease in μ_{eff} for the tetrahedral Co^{++} complexes in $(CoCl_4)^=$ as T decreases has been observed.

It is of interest to note that the large orbital contribution in octahedrally co-ordinated cobaltous salts, e.g. $[Co(H_2O)_6]Cl_2$, is associated with marked anisotropy in the susceptibility. On the other hand, the blue tetrahedrally co-ordinated salts are nearly isotropic. Thus, Krishnan and Mookherjee (1938) found that anisotropy in blue Cs_2CoCl_4 was only about 5%, whereas in the pink hexahydrated cobaltous salts it is of the order of 30%. Data for tetrahedrally co-ordinated Ni^{++} are scarce and contradictory. Similarly, no certain cases of tetrahedral co-ordination to Cu^{++} has been reported. However, some new five-covalent complexes of bivalent copper, which have a very large orbital contribution ($\mu_{eff}=2 \cdot 6$ B.M.), may result from a crystalline field which is effectively the same as that produced by tetrahedral co-ordination (Craig, Harris and Nyholm, 1955).

As yet only in the case of bivalent cobalt complexes has any serious examination been made of the use of the orbital contribution as a guide to stereochemistry. Broadly speaking, a moment between $4 \cdot 3$ and $4 \cdot 75$ indicates tetrahedral co-ordination, whereas a moment in excess of $4 \cdot 85$ indicates an octahedral arrangement. It is obvious that uncertainty must remain for complexes having a μ_{eff} in the vicinity of $4 \cdot 7$–$4 \cdot 8$ B.M. It has become increasingly apparent that, since the field constant is affected by several other factors besides the stereochemistry, these must be borne in mind. These factors include the charge on the complex ion, the attachment of heterogeneous groups, e.g. $(CoCl_2, X_2)$, the electronegativity of attached groups, and the possibility of longer range electrical forces arising from atoms surrounding the complex. Data available at present suggest that the higher the electronegativity of the attached group the larger the orbital contribution.

A simple illustration of the application of these ideas to a stereochemical problem is provided by a study of the magnetic moments of the complexes of cobaltous halides with aniline (An) (Gill and Nyholm, 1955). It is possible to prepare blue compounds having the formulae $CoCl_2.2An$, $CoBr_2.2An$ and $CoI_2.2An$. In addition a pink di-alcoholate of the chloride $CoCl_2.2An.2EtOH$ and of the bromide can be isolated. If the alcohol in these really co-ordinated with the Co atom to form an octahedral complex, magnetic moments greater than $4 \cdot 8$ B.M. are expected. On the other hand, if the blue complexes CoX_2An_2 are really tetrahedral then they should have moments $<4 \cdot 7$ B.M. The actual values given in Table 9 indicate that this is so, and support the hypothesis that the $CoX_2.2An$ ($X=Cl$, Br and I) complexes are tetrahedral and the di-alcoholate octahedral. However, as an apparent exception to the above generalizations the thiocyanate $Co(SCN)_2.2An$ is found to be *pink* in the solid state with a magnetic moment ($5 \cdot 11$ B.M.) corresponding to an octahedral complex. This can be explained, however, by postulating that the $Co(SCN)_2.2An$ is polymerized in the solid state, the –SCN group being co-ordinated to a second cobalt atom.

This kind of behaviour occurs in the compound $HgCo(CNS)_4$, the $-CNS$ being co-ordinated to the mercury atom as well as the cobalt, although in this instance the Co atom retains its tetrahedral configuration. A test of this hypothesis is provided by the colour and magnetic moment of the $Co(SCN)_2.2An$ complex in acetone. The polymer might be expected to dissociate into monomeric tetrahedral $Co(SCN)_2.2An$ molecules if it dissolves. The fact that the solution is blue and has a much smaller magnetic moment (4.62 B.M.) is strong evidence for a change over to the tetrahedral configuration in solution.

Another interesting application is in connection with the structures of the *blue* and *violet* forms of cobaltous chloride bis-pyridine complex, $CoCl_2.2Py$ (Barclay, Christie and Nyholm, 1955). The violet form has a magnetic moment of 5.24 B.M. suggesting octahedral co-ordination (Barkworth and Sugden, 1937). This form exists only in the solid state and cannot be dissolved in solvents

TABLE 9.

Magnetic Moments and Other Physical Properties of Cobaltous Aniline Complexes.

Complex.	Colour in Solid State.	μ_{eff} in Solid State. B.M.	Colour in Acetone Solution. (3%.)	μ_{eff} in Acetone Solution. (3%.)
$CoCl_2.2An$	Blue	4.40	Blue	4.49
$CoBr_2.2An$	Blue	4.46	Blue	4.49
$CoI_2.2An$	Green-blue	4.61	Green	4.43
$CoCl_2.2An.2C_2H_5OH$.. ..	Pink	5.0	—	—
$CoBr_2.2An.2C_2H_5OH$ ..	Pink	5.0	—	—
$Co(CNS)_2.2An$	Pink	5.11	Blue	4.62

without a changeover to the blue form taking place. The blue form, on the other hand, has a magnetic moment of 4.51 B.M. and 4.47 B.M. in the solid state and in nitrobenzene respectively. In the latter solvent it is monomeric and a non-electrolyte and undoubtedly exists as tetrahedral $CoCl_2.2Py$ molecules. Under the circumstances, it is reasonable to suggest that the violet form has a polymeric structure with octahedrally co-ordinated cobaltous atoms connected together by halogen bridges in an infinite polymeric lattice.

It is probable that as more data on Fe, Cu and Ni salts bearing on the relationship between orbital contribution and stereochemistry become available the orbital contribution will serve as a useful guide to the stereochemistry of these ions also.

(2) *Orbital Contribution in " Covalent " Complexes.*

Although the theoretical picture is much less developed, the use of the size of the orbital contribution to assist in determining the stereochemistry of " covalent " complexes, i.e. those in which electron pairing occurs, looks promising, but to a more limited extent. The kind of variation which is observed in the orbital contribution of complexes containing one unpaired electron is illustrated by the following octahedral complexes*: Fe^{III}, e.g. $K_3Fe(CN)_6$, $\mu_{eff} = 2.35$ B.M. ; Co^{II}, e.g. $K_2CaCo(NO_2)_6$, $\mu_{eff} = 1.89$ B.M. ; Ni^{III}, e.g. $[Ni(Diarsine)_2Cl_2]Cl$, $\mu_{eff} = 1.92$ B.M. A particularly interesting situation arises with Co^{II} because two kinds of complex both containing one unpaired electron

* Spin only moment for single unpaired electron $= 1.73$ B.M.

are known—octahedral six-covalent and planar four-covalent. A survey (Figgis and Nyholm, 1954) reveals that the value of μ_{eff} for a series of octahedral complexes is in the range $1\cdot8$–$1\cdot95$ B.M. In marked contrast, however, the square planar complexes have a μ_{eff} in the range $2\cdot1$–$2\cdot9$ B.M. with a mean value of about $2\cdot5$ B.M. It is proposed that, even though a theoretical treatment is not yet available, the size of the orbital contribution might be used empirically as a guide to stereochemistry. Of course, if one can ascertain whether a " covalent " Co^{II} complex is four- or six-covalent, the problem of the stereochemistry is largely solved. However, there are circumstances, particularly with insoluble Co^{II} complexes, in which a molecular weight cannot be determined. It is in situations like this that the above empirical rules may prove useful.

In the foregoing survey we have endeavoured to summarize the position at present concerning the use of magnetism as a means of determining the shape of inorganic molecules. The value and limitations of the Pauling approach based solely on the number of unpaired electrons has been indicated ; it seems that we may not anticipate any noteworthy advances in this direction until and unless theories governing the more exact relationship between energy levels, stereochemistry and hybridized bonding orbitals are much further advanced. However, the alternate crystal field approach is most promising. The information provided by spectra concerning energy levels is most valuable and is leading to more quantitative information about metal complexes. Also the data which are emerging from the studies of paramagnetic resonance when allied with the above are leading to remarkable advances. Finally, both diamagnetism and the size of the orbital contribution to magnetic moments offer most promising fields for further investigation.

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THE ESSENTIAL OIL OF *BACKHOUSIA MYRTIFOLIA* HOOKER *ET* HARVEY.

PART III. SINGLE-TREE STUDIES ON PHYSIOLOGICAL FORMS FROM QUEENSLAND.

By R. O. Hellyer,
H. H. G. McKern
and J. L. Willis.

Museum of Applied Arts and Sciences, Sydney.

SUMMARY.

The examination of the volatile oils from eighteen individual trees of *Backhousia myrtifolia* from south-eastern Queensland has demonstrated the existence of four forms of this species, each recognized by the presence in its oil of a characteristic phenol ether as the principal constituent. The four forms are (1) the elemicin form (regarded as the " Type ") ; (2) the *iso*-elemicin form ; (3) the methyl eugenol form ; (4) the methyl *iso*-eugenol form. The presence of *iso*-elemicin as a minor component has been shown in oils of the methyl *iso*-eugenol form. Variations in the physical constants of the *iso*-elemicin fractions are attributed to *cis-trans* isomerism, and the 1,3,5-trinitrobenzene derivative of this phenol ether is described.

In Part II, Penfold, McKern and Spies (1953) recorded the existence of physiological forms within the species *Backhousia myrtifolia* Hooker *et* Harvey. In the present paper, the results of the examination of the volatile oils distilled from the foliage of eighteen individual trees growing in south-east Queensland has confirmed the occurrence of at least three variants from the elemicin form (regarded as the " Type "). These are (1) a form whose oil consists predominantly of *iso*-elemicin (3,4,5-trimethoxypropenyl benzene) ; (2) a form containing methyl eugenol (3,4-dimethoxyallyl benzene) as major constituent in the oil ; and (3) a form yielding an oil containing methyl *iso*-eugenol (3,4-dimethoxypropenyl benzene) as characteristic component.

The Elemicin Form (the " Type "). It is of interest to observe that the Type, originally described by Penfold (Part I, 1922) from southern New South Wales localities, extends to southern Queensland, and is to be found growing intermingled with its forms under similar environmental conditions. Oils from six " Type " trees were examined, three from Fraser Island, and three from the mainland, and within the limits imposed by the small quantities of oil available (6·5 to 76·0 ml. per tree ; total oil, 176·5 ml.), there appears to be no other phenol ether present. A special search for *iso*-elemicin was made in the fractional distillation residues, but no evidence could be found for its presence in quantities of the order of 1% to 2%. A similar working-up of a southern N.S.W. oil gave likewise only elemicin as the highest-boiling component. The " Type " oil thus appears to preserve a uniformity of composition over its geographical range.

The iso-*Elemicin Form.*   Four trees (three from Fraser Island and one from Cooloolabin on the mainland) have been shown to yield oils containing *iso*-elemicin in quantity as a characteristic component.   Unfortunately, a rigorous examination for other phenol ethers could not be made on the three Fraser Island oils (4, 13 and 5 ml. of oil available respectively), but the fractionation of oil from No. 3 tree, Cooloolabin (39 ml.) did not disclose any notable amount of other phenol ethers.

The Methyl Eugenol Form.   The location of a tree of this form is of particular interest, inasmuch as its probable existence was predicted on the basis of the detection of methyl eugenol during the examination of the original Fraser Island " bulk-cut " oil (Part II, Summary).   Again it is not possible to exclude the possibility of the occurrence of small percentages of other phenol ethers associated with the methyl eugenol, since only 22 ml. of crude oil was available for fractionation.

The Methyl iso-*Eugenol Form.*   Oils from seven trees of this form (six from Fraser Island, one from Cooloolabin, were available in quantity ranging from 19 to 65 ml.   Although methyl *iso*-eugenol is the major constituent of this oil, exhaustive fractional distillation of the higher-boiling portions from the six Fraser Island oils demonstrated the presence of a small quantity of *iso*-elemicin (of the order of an average of 2%) in the original crude oils.   However, in the case of the oil from tree No. 5, Cooloolabin, the *iso*-elemicin content was of the order of 15%.

In Part II reference was made to the high refractive index of the *iso*-elemicin fraction, and the opinion was expressed that it may be due to the presence of one of the isomeric asarones (2,4,5-trimethoxypropenylbenzene).   In point of fact, fractions were isolated during the present work which had physical constants agreeing very closely with those recorded by Rao and Subramaniam (1937) or β-asarone :

Tree 8, Fraser Island :	b_{10} 157°–161°	d_{15}^{15} 1·090	n_D^{20} 1·5574
Tree 3, Cooloolabin, Frn. 7 :	b_{10} 160°–161°	d_{15}^{15} 1·090	n_D^{20} 1·5570
,, ,, Frn. 8 :	b_{10} 161°–162°	d_{15}^{15} 1·089	n_D^{20} 1·5561
β-asarone :	b_{12} 162°–163°	d_{30}^{30} 1·082	n_D^{20} 1·5552

However, in the case of Tree 3 (Cooloolabin), fractions 7 and 8 yielded 3,4,5-trimethoxybenzoic acid on permanganate oxidation, no trimethoxyphenyl-acetic acid being found in the reaction mixture.   They also gave the dibromide of m.p. 91·5°–92·0°, identical with that yielded by fraction 5 of the same oil, and which had physical constants (b_{10} 153°–157° ; d_{15}^{15} 1·069 ; n_D^{20} 1·5417) more closely agreeing with the rather sparse data available for *iso*-elemicin* (e.g. Semmler (1908), b_{10} 153°–156° ; d_{20} 1·073 ; n_D^{20} 1·54679).   Since the molecular weight found rules out dimerization, it would appear that *cis-trans* isomerism is responsible for the wide variations in the physical data found for the *iso*-elemicin isolated from these oils.   During the alkali-isomerization of elemicin in this Laboratory, similarly varying physical data have been recorded for the product.   Details of this work will appear elsewhere.   The other substituted styrene observed in these oils, methyl *iso*-eugenol, appears from its melting-point (16°) and other physical constants to be present largely as the *trans*-form.

Further differentiation of fractions 7 and 8 above from asarone lies in the 1,3,5-trinitrobenzene derivative which melts at 89°–90°.   This derivative does not appear to have been previously described, and should be of use in the quick

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* Compare also F. Mauthner's specimen (*Ann.* **414** (1917), 252) which had b_{10} 153°–156°, d_{20} 1·077, n_D^{20} 1·54735.

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identification of *iso*-elemicin. Sudborough and Beard (1911) described two derivatives of asarone with this reagent, $C_{12}H_{16}O_3$, $C_6H_3O_6N_3$, m.p. 77°–78°, and $C_{12}H_{16}O_3$, $2C_6H_3O_6N_3$, m.p. 92·5°.

Owing to the limited quantity of the fore-runs, no attempt has yet been made to determine the nature of the minor constituents of these oils, since they represent a complex mixture of hydrocarbons, alcohols, esters and, it is suspected, an oxide. However, by combining the fore-runs from the fractional distillation of the six Fraser Island methyl *iso*-eugenol oils, it was possible to demonstrate the presence of α-pinene.

EXPERIMENTAL.

(In each case the essential oils were heavier than water, and were obtained by the steam-distillation of the leaves and terminal branchlets, cut as for commercial distillation. The physical constants of the oils were determined after drying with anhydrous sodium or magnesium sulphate. All melting-points are uncorrected.)

TABLE 1.
Crude Oils of Elemicin Form of B. myrtifolia.

Locality.	Oil Yield.	d_{15}^{15}.	n_D^{20}.	$α_D$.
Fraser Island, 31/8/53,　No.　9　　..	0·30%	1·0355	1·5218	+0·75°
,,　　　　,,　　　　,,　　　No. 10　　..	0·31%	1·0500	1·5252	+0·04°
,,　　　　,,　　　　,,　　　No. 12　　..	0·10%	1·0240	1·5226	Inactive
Cooloolabin, 28/1/54,　No.　1　　..	0·73%	1·0430	1·5214	+0·52°
,,　　　　　　,,　　　　No.　2　　..	0·40%	1·0579	1·5258	+0·20°
,,　　　　　　,,　　　　No.　6　　..	0·32%	1·0500	1·5262	+0·10°
Bateman's Bay,　N.S.W.,　11/9/53　..	0·46%	1·0350	1·5202	—2·10°

Elemicin Form.

The crude oils, each from a single tree, had the physical constants shown in Table 1. Each oil was fractionally distilled at 10 mm., and in each case a main fraction of fairly constant boiling point was obtained. These fractions were collected over the boiling range 143°–149° at 10 mm., and had d_{15}^{15} 1·073–1·075, n_D^{20} 1·5291–1·5300. Each was either optically inactive or nearly so. On uniting all these main fractions and re-fractionating, no significant separation occurred. From the three Fraser Island trees a product was obtained of b_{10} 144°–145°; d_{15}^{15} 1·076; n_D^{20} 1·5299, optically inactive. Seven grammes was oxidized by $KMnO_4$ (15·4 g.), KOH (2·1 g.), water (490 ml.) and ice (490 g.). From the reaction product was isolated an *acid* of m.p. 169°–170°, undepressed on admixture with a specimen of synthetic 3,4,5-trimethoxybenzoic acid. 0·4100 g of the acid required 19·4 ml. of 0·1N. NaOH for neutralization. Molecular weight for a monobasic acid, 211·9; 3,4,5-trimethoxybenzoic acid requires 212·2. From the mother-liquor from the precipitation of the above acid was obtained an *acid* of m.p. 114°–117°, identical with 3,4,5-trimethoxyphenylacetic acid.

From the three mainland trees (Cooloolabin), the following product was isolated: b_{10} 145°–146°; d_{15}^{15} 1·075; n_D^{20} 1·5303; $α_D$ ±0°. Oxidation with permanganate as just described again resulted in the formation of an *acid* of m.p. 169°–170°, identical with 3,4,5-trimethoxybenzoic acid, as well as an *acid* of m.p. 115°–117°, identical with 3,4,5-trimethoxyphenylacetic acid.

Still-pot residues (3·6 ml.) from the Cooloolabin oils (total volume, 106 ml.) on re-distillation at 10 mm. gave 1·6 ml. of an oil having b_{10} 144°–165°; d_{15}^{15} 1·074; n_D^{20} 1·5302; $α_D$ ±0°; whilst similar treatment of the residues (10·5 ml.) from the Fraser Island oils (total volume fractionated, 70·5 ml.) gave a main fraction of 8 ml. (b_{10} 146°–149°; n_D^{20} 1·5300) and a final fraction of 1 ml. (b_{10} 149°–157°; n_D^{20} 1·5295; $α_D$ ±0°). Hence significant amounts of higher-boiling substances

are absent. A similar experiment was carried out on an elemicin type oil from Bateman's Bay (see Table 1) in southern New South Wales ; 100 ml. crude oil fractionally distilled at 10 mm. gave a last fraction (63 ml.) distilling at 144°–147° and had d_{15}^{15} 1·069 ; n_D^{20} 1·5282 ; α_D ±0°. The still-pot residue of 8·5 ml. (d_{15}^{15} 1·056 ; n_D^{20} 1·5257) was filtered from a small amount of paraffin wax, m.p. 63°–64°, and the filtrate (6 ml.) re-distilled at 10 mm. to give two main fractions (d_{15}^{15} 1·066 ; n_D^{20} 1·5273 ; 3 ml., and d_{15}^{15} 1·060 ; n_D^{20} 1·5263 ; 1·3 ml.). It thus appears that no other phenol ether accompanies the elemicin in any quantity.

Iso-elemicin Form.

The crude oils, each from a single tree, were found to possess the physical constants given in Table 2.

TABLE 2.

Crude Oils of Iso-Elemicin Form of B. myrtifolia *from Queensland.*

Locality.	Oil Yield.	$d_{15}^{15}.$	$n_D^{20}.$	$\alpha_D.$
Fraser Island, 23/8/53, No. 3 ..	0·08%	1·0290	1·5358	—0·20°
,, ,, 31/8/53, No. 8 ..	0·14%	1·0520	1·5450	Inactive (25 mm.)
,, ,, 31/8/53, No. 11 ..	0·10%	1·0270	1·5306	+0·80°
Cooloolabin, 28/1/54, No. 3 ..	0·40%	1·0549	1·5427	+0·70°

Tree No. 3, Fraser Island.   4 ml. crude oil distilled at 10 mm. gave a fore-run of 0·6 ml. (b_{10} 45°–156° ; n_D^{20} 1·5206) and a main fraction of 2·1 ml. (b_{10} 156°–157° ; d_{15}^{15} 1·078 ; n_D^{20} 1·5491 ; α_D ±0°).   This main fraction (1 g.), brominated according to Semmler (1908), yielded a copious mass of white prisms of m.p. 90°–90·5° from petroleum (50°–60°).   Cook, Johnston and Loudon (1948) found 92°–93°, and Semmler 88°–89° for the melting-point of this bromide.

Tree No. 8, Fraser Island.   13 ml. crude oil distilled at 10 mm. gave 4 ml. of fore-run (80°–156°).   The main fraction (b_{10} 157°–161° ; d_{15}^{15} 1·090 ; n_D^{20} 1·5574 ; α_D ±0°) likewise yielded a *bromide* m.p. 91°–91·5°, undepressed on admixture with an authentic specimen of *iso*-elemicin dibromide.

TABLE 3.

Fractional Distillation of 10 mm. *of Crude Oil of Tree No. 3, Cooloolabin, Queensland.*

Fraction.	Boiling Range.	Volume. (ml.)	$d_{15}^{15}.$	$n_D^{20}.$	$\alpha_D.$
1	60°– 80°	0·5	—	1·4861	—
2	80°–120°	1·0	—	1·4760	—
3	120°–147°	4·5	0·9367	1·5054	+1·68°
4	147°–153°	1·7	—	1·5267	+2·48°
5	153°–157°	7·0	1·069	1·5417	+1·00°
6	157°–160°	4·0	1·086	1·5520	+1·00°
7	160°–161°	6·0	1·090	1·5570	Inactive.
8	161°–162°	8·0	1·089	1·5561	Inactive
Residue	—	0·5	—	—	—

Tree No. 11, Fraser Island.   5 ml. of crude oil distilled at 10 mm. gave 1·8 ml. of fore-run (b_{10} 136°–156° ; d_{15}^{15} 0·9970 ; n_D^{20} 1·5266), and 1·8 ml. of a fraction (b_{10} 156°–160° ; d_{15}^{15} 1·077 ; n_D^{20} 1·5470) which yielded a *bromide*, m.p. 90°–91° undepressed by admixture with authentic *iso*-elemicin dibromide.

Tree No. 3, Cooloolabin.   39 ml. of crude oil was fractionally distilled at 10 mm. to give the fractions whose physical data are recorded in Table 3.   Fraction 5 (1 g.) brominated according

to Semmler (*loc. cit.*) gave a *bromide* of m.p. 90·5°–91·5°, undepressed on admixture with *iso*-elemicin dibromide. Fractions 7 and 8 were regarded as homogeneous and were combined. Found: C, 69·51%; H, 7·66%; O, 22·8%. $C_{12}H_{16}O_3$ requires C, 69·18%; H, 7·74%; O, 23·0%. Molecular weight, 202. $C_{12}H_{16}O_3$ requires 208. s-*Trinitrobenzene derivative*: Fractions 7 and 8 (1·581 g.) in benzene (5 ml.) mixed with s-trinitrobenzene (1·610 g.) dissolved in warm benzene (10 ml.). Heated on the steam-bath a few minutes, cooled and allowed to evaporate spontaneously. Orange crystals, m.p. 87°–89·5°, raised to 89°–90° by repeated re-crystallization (needles) from absolute alcohol. N found, 10·15, 10·01%. Calculated for $C_{18}H_{19}O_9N_3$, 10·00%. Two similar preparations from authentic *iso*-elemicin gave melting points of 89·5° to 90·5° and 89°–90° respectively. *Bromination* of fractions 7 and 8 by Semmler's procedure gave a *bromide*, m.p. 91·5°–92°, undepressed by admixture with *iso*-elemicin dibromide. Oxidation by alkaline permanganate of 5 g. of the combined fractions 7 and 8 by the procedure of Fabinyi and Széki (1906) gave 3·4 g. of an *acid*, m.p. 169°–169·5° from benzene, undepressed on admixture with a specimen of synthetic 3,4,5-trimethoxybenzoic acid of m.p. 169°–169·5°. No other oxidation product, neutral or acidic (other than acetic acid) could be found in the reaction-mixture.

Methyl Eugenol Form.

Tree No. 4, Cooloolabin, 28/1/54, yielded an oil of d_{15}^{15} 1·0248; n_D^{20} 1·5271; α_D —0·10° and soluble in 0·7 of its volume of 70% w/w alcohol. Fractional distillation at 10 mm. of all the oil available (22 ml.) gave a fore-run of 1·5 ml. (n_D^{20} 1·4950) and four successive fractions (d_{15}^{15} 1·035 to 1·042; n_D^{20} 1·5319 to 1·5334; α_D ±0°) over a boiling-range of 120° to 138°. The fraction (b_{10} 125°–130°; d_{15}^{15} 1·042; n_D^{20} 1·5334; α_D ±0°) (2 g.) in dry ether (20 ml.) yielded with bromine (1·2 ml.) a *bromide*, m.p. 77° from absolute alcohol, undepressed by an authentic specimen of the dibromide of methyl eugenol. The same fraction (5 g), oxidized with permanganate in acetone solution according to the procedure of Luff, Perkin and Robinson (1910), gave an *acid* of m.p. 179°–180°, undepressed on admixture with an authentic specimen of veratric acid. From the mother-liquor was isolated an *acid* of m.p. 80°–81°, identical with homoveratric acid.

The fore-run (1·5 ml.) and still-pot residue (0·5 ml.; n_D^{20} 1·5300) were not further examined.

Methyl iso-*Eugenol Form.*

The crude oils, each from a single tree, had the physical data shown in Table 4.

TABLE 4.

Crude Oils of Methyl iso-*Eugenol Form of* B. myrtifolia *from Queensland.*

Locality.	Oil Yield.	d_{15}^{15}.	n_D^{20}.	α_D.
Fraser Island, 23/8/53, No. 1 ..	0·31%	1·0295	1·5491	—0·25°
,, ,, ,, No. 2 ..	0·32%	1·0070	1·5398	+0·25°
,, ,, ,, No. 4 ..	0·33%	1·0355	1·5544	+0·40°
,, ,, ,, No. 5 ..	0·14%	1·0195	1·5479	—0·30°
,, ,, ,, No. 6 ..	0·28%	1·0245	1·5490	+0·40°
,, ,, 31/8/53, No. 7 ..	0·53%	1·0340	1·5570	+0·53°
Cooloolabin, 28/1/54, No. 5 ..	0·43%	1·0420	1·5516	+0·20°

Each of the six Fraser Island oils was fractionally distilled at 10 mm., and in each case resolution into a main fraction comprising the bulk of the oil was effected. These main fractions were collected over the range 139°–155°, and had d_{15}^{15} 1·051 to 1·064; n_D^{20} 1·5622 to 1·5681; α_D —0·25° to +0·16°. Refractionation failed to produce any significant separation, and the combined main fraction had b_{10} 141°–142°; d_{15}^{15} 1·056; n_D^{20} 1·5675; α_D ±0°. This product (2 g.) in dry ether (20 ml.) gave with bromine (0·6 ml.) at 0° a *bromide*, m.p. 102°–102·5° from

ether.   Seven grammes on oxidation with aqueous permanganate gave a practically quantitative yield of an *acid*, m.p. 181·5° to 182°, undepressed by admixture with an authentic specimen of veratric acid.   Homoveratric acid could not be isolated from the reaction product.

Determination of iso-Elemicin.   The still-pot residues from the preceding six fractionations of a total of 254 ml. of crude oils were united to give 19 ml., from which the lower-boiling portion (chiefly methyl*iso*eugenol) was slowly fractionated off at 10 mm.   The 5 ml. still-pot residue (2% of the original oils) was then resolved at 1 mm. into two fractions, the first (2·2 ml.) had d_{15}^{15} 1·067 and n_D^{20} 1·5475; whilst the second (0·4 ml.) had n_D^{20} 1·5462.   These two fractions were united and from the mixture was prepared a *bromide*, m.p. 89°–89·5°, undepressed by admixture with *iso*-elemicin dibromide.

Tree No. 5, Cooloolabin.   38 ml. of crude oil was fractionally distilled at 10 mm. to give the fractions shown in Table 5.   Fraction 5 (2 g.) yielded a *bromide*, m.p. 101° to 101·5°, undepressed by admixture with methyl *iso*-eugenol dibromide.   Oxidation of 5 g. of the same fraction by means of aqueous permanganate gave an *acid* m.p. 182°, undepressed on admixture with veratric acid.   0·5000 g. required 27·5 ml. 0·1N NaOH.   Molecular weight for a monobasic acid, 182·0.   Veratric acid requires 181·9.

TABLE 5.

Fractional Distillation at 10 mm. of Crude Oil of Tree No. 5, Cooloolabin, Queensland.

Fraction.	Boiling Range.	Volume (ml.)	d_{15}^{15}.	n_D^{20}.	α_D.
1	58°– 80°	1·0	—	1·4757	—
2	80°–110°	1·0	—	1·4769	—
3	110°–140°	4·5	0·9583	1·5119	—1·20°
4	140°–142°	9·0	1·049	1·5611	Inactive.
5	142°–145°	10·0	1·058	1·5646	,,
6	145°–150°	6·5	1·063	1·5619	,,

The bulk of the remainder was then distilled over without column as a single fraction designated 7.

| 7 | 160°–164° | 4·0 | 1·084 | 1·5570 | — |
| Residue | — | 1·0 | — | — | — |

Fraction 7 (1 g.) yielded a *bromide*, m.p. 91·5°–92·0°, undepressed on admixture with an authentic specimen of *iso*-elemicin dibromide.   Oxidation of fraction 7 (2·5 g.) with aqueous alkaline permanganate gave an excellent yield of an *acid* m.p. 170°–171°, undepressed by admixture with 3,4,5-trimethoxybenzoic acid.   0·6687 g. required 31·5 ml. 0·1N NaOH. Molecular weight for a monobasic acid, 212·0.   3,4,5-Trimethoxybenzoic acid requires 212·3.

Lower-boiling Fractions.   The combined fore-runs of all six Fraser Island oils totalled 20 ml., and were re-fractionated at 10 mm.   In the " dry-ice "-acetone trap interposed between the fractional distillation apparatus and the vacuum pump was condensed 1 ml. of liquid, n_D^{20} 1·4654 and α_D —2·4°.   It yielded a *nitrosochloride* of m.p. 110·5° undepressed on admixture with a nitrosochloride of m.p. 110·5° prepared from an authentic specimen of racemic α-pinene.   Permanganate oxidation of the three successive terpenic fractions (2, 4 and 3 ml. respectively) yielded *pinonic acid* (semicarbazone, m.p. 204°).

members of the Fraser Island Forest Station staff ; to Mr. A. Anderson of the Maryborough Forestry Office ; and to Mr. H. Holt, Forest Overseer at Cooloolabin.   We are also under obligation to Messrs. J. Dunbier and M. Whyte of this Institution for much help in the analytical determinations, steam-distillations, and other laboratory assistance.   Combustion micro-analyses and molecular weight determinations were carried out by the Division of Industrial Chemistry of the Commonwealth Scientific and Industrial Research Organisation, Melbourne.   We are indebted to the Director (Mr. A. R. Penfold) and Trustees of the Museum for permission to publish this work.

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OCCULTATIONS OBSERVED AT SYDNEY OBSERVATORY DURING 1954.

By K. P. Sims, B.Sc.

The following observations of occultations were made at Sydney Observatory with the 11½-inch telescope.   A tapping key was used to record the times on a chronograph.   The reduction elements were computed by the method given in the Occultation Supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there.   The necessary data were taken from the *Nautical Almanac* for 1954, the Moon's right ascension and declination (hourly

TABLE I.

Serial No.	N.Z.C. No.	Mag.	Date.		U.T.	Observer.
					h m s	
288	518	5·9	Jan.	14	12 55 36·1	R
289	844	5·7	Jan.	16	12 41 06·6	R
290	849	6·5	Jan.	16	13 46 32·6	R
291	750	6·9	Mar.	11	10 47 59·9	R
292	—	8·9	Mar.	23	16 03 52·2	S
293	1023	6·5	Apr.	9	8 48 12·1	S
294	1688	6·3	Apr.	15	13 01 15·7	W
295	1245	7·5	May	8	11 3 57·9	W
296	1726	6·9	June	9	13 46 17·1	R
297	2134	6·1	June	13	9 59 02·0	W
298	2442	5·9	Aug.	9	10 48 24·1	W
299	2443	5·8	Aug.	9	11 00 30·2	W
300	2459	7·2	Aug.	9	15 29 33·6	W
301	2607	5·9	Aug.	10	15 48 10·9	W
302	2747	5·0	Aug.	11	12 43 32·0	W
303	2490	5·4	Oct.	3	11 54 34·3	W
304	—	6·9	Oct.	3	11 54 45·2	W
305	2630	5·1	Oct.	4	12 03 50·8	W
306	2779	3·9	Oct.	5	11 51 41·5	W
307	2778	6·9	Oct.	5	12 07 26·0	W

table) and parallax (semi-diurnal table) being interpolated therefrom.   No correction was applied to the observed times for personal effect but a correction of −0·00152 hour was applied before entering the ephemeris of the Moon. This corresponds to a correction of −3″·0 to the Moon's mean longitude.

Table I gives the observational material.   The serial numbers follow on from those of the previous report (Sims, 1954).   The observers were H. W. Wood (W), W. H. Robertson (R) and K. P. Sims (S).   The phase observed was disappearance at the dark limb in all cases except 292, which was a reappearance

at the dark limb. Table II gives the results of the reductions which were carried out in duplicate. The N.Z.C. numbers given are those of the *Catalog of* 3539 *Zodiacal Stars for the Equinox* 1950·0 (Robertson, 1940), as recorded in the *Nautical Almanac.*

TABLE II.

Serial No.	Luna-tion.	p	q	p^2	pq	q^2	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of	
										$\Delta\alpha$	$\Delta\delta$
288	384	+ 60	—80	36	—48	64	—0·6	—0·4	+0·5	+10·1	—0·67
289	384	+ 88	+48	77	+42	23	—1·2	—1·1	—0·6	+12·0	+0·45
290	384	+ 90	—44	81	—40	19	+0·8	+0·7	—0·4	+11·9	—0·47
291	386	+ 85	+52	73	+44	27	—0·6	—0·5	—0·3	+11·3	+0·55
292	386	— 96	—28	92	+27	8	—0·9	+0·9	+0·3	—14·0	—0·03
293	387	+ 27	—96	7	—26	93	—1·8	—0·5	+1·7	+ 1·5	—0·99
294	387	+ 83	—56	69	—46	31	+1·6	+1·3	—0·9	+ 7·6	—0·86
295	388	+ 82	—57	68	—47	32	+1·8	+1·5	—1·0	+ 8·7	—0·79
296	389	+ 26	+97	7	+25	93	—0·5	—0·1	—0·5	+ 9·5	+0·77
297	389	+ 55	—84	30	—46	70	+1·5	+0·8	—1·3	+ 4·6	—0·95
298	391	+100	+ 3	100	+ 3	0	0·0	0·0	0·0	+13·6	0·00
299	391	+ 91	+42	82	+38	18	—1·9	—1·7	—0·8	+12·5	+0·40
300	391	+ 80	—60	64	—48	36	+0·6	+0·5	—0·4	+10·8	—0·60
301	391	+ 92	—40	84	—37	16	—2·2	—2·0	+0·9	+13·0	—0·32
302	391	+ 89	+46	79	+41	21	—0·8	—0·7	—0·4	+10·9	+0·61
303	393	+ 86	+50	75	+43	25	—1·0	—0·9	—0·5	+11·8	+0·51
304	393	+ 86	+51	74	+44	26	—2·5	—2·2	—1·3	+11·6	+0·52
305	393	+ 99	—14	98	—14	2	+0·9	+0·9	—0·1	+13·7	—0·04
306	393	+ 99	+14	98	+14	2	—0·5	—0·5	—0·1	+13·1	+0·33
307	393	+ 41	+91	17	+37	83	—1·0	—0·4	—0·9	+ 3·0	+0·98

    The Stars involved in occultations 292 and 304 were not in the *Nautical Almanac* list ; they are G.C. 20111 and G.C. 23343. The apparent place of G.C. 20111 was R.A. 14ʰ 54ᵐ 47ˢ·87, Dec. —21° 12′ 36″·8, and that of G.C. 23343 was R.A. 17ʰ 15ᵐ 15ˢ·44, Dec. —24° 14′ 15″·3.

REFERENCES.

Robertson, A. J., 1940. Astronomical Papers of the American Ephemeris, Vol. X, Part II.
Sims, K. P., 1954. THIS JOURNAL, 88, 22 ; Sydney Observatory Papers No. 21.

ON SOME SPECIES OF *PHYLLOTHECA*.

By JOHN A. TOWNROW,

Botany Department, University of Reading.

Communicated by H. O. Fletcher.

(With Plate I and five Text-figures.)

ABSTRACT.

Four species of *Phyllotheca* are described : *P. australis* Brongniart, the Type species ; *P. indica* Bunbury, a species sometimes united with *P. australis* hitherto ; *P. sahnii* Saksena, a species with a large saucer-shaped leaf-sheath ; and *P. brookvalensis* n.sp., a species in some respects intermediate between *Phyllotheca* and *Neocalamites*. A species of *Equisetites* (*Equisetum*), *E. minuta* (Arber), originally placed in *Phyllotheca* but now removed, is also described.

The cone of *Phyllotheca australis* is described. It proves to be unusual in having branched sporangiophores.

Some discussion of the affinities of *Phyllotheca* is offered, both of species known fertile, and of those known only in the sterile condition.

INTRODUCTION.

The genus *Phyllotheca* is now a large one (with some twenty species) and is familiar and locally common, but still remains a vague assemblage. One of the difficulties has been that the type species *P. australis* has remained little known. This is now described in considerable detail. Its cone proves to be remarkable, and while showing important features of previously known kinds it has one of its own—branched sporangiophores—which is most exceptional in the Equisetales, and thus of great morphological interest.

Phyllotheca Brongniart.

Selected references :

1828   *Phyllotheca* Brongniart, p. 152. Description of the Type, no figures.
1847   *Phyllotheca* : McCoy, pp. 156–159, pl. 9, figs. 1–7. Description and figures of *P. australis* with (?) cone.
1879   *Phyllotheca* : Schmalhausen, pp. 62–74, pl. 1, figs. 1–3, 9, 16, pl. 10, not pl. 9, fig. 17. Cone of *P. deliquescens*.
1898   *Phyllotheca* : Seward, pp. 281–291, with text-figures. General discussion of the genus.
1899   *Phyllotheca* : Zeiller, pp. 65–69, pl. 5, figs. 2–12. *P. rallii* with its cone described.
1905   *Phyllotheca* : Arber, pp. 16–30, pl. 2, figs. 7, 8, and text-figs. Description of several species and discussion of the genus.
1927   *Phyllotheca* : Gothan, p. 150, pl. 18, figs. 6–8. *P. uluguruana* described.
1927   *Phyllotheca* : Hirmer, pp. 461–463, figs. 557–560 on p. 462. Discussion of the genus.

Diagnosis (Emended).

Plants with main stems up to 2 cm. in diameter, showing fine longitudinal ribs, only slightly lignified, nodes marked by transverse furrows. Main stems bearing branches, few or whorled, smaller than main stems but otherwise similar, neither main stem nor branches bearing persistent leaves. Leafy shoots borne on main stems or branches, few or whorled, less than 1 cm. in diameter, with fine longitudinal ribs, and hardly lignified. Leaves spreading, thin, flat, margins entire, single midrib (often indistinct), joined basally in a sheath seldom more than half as long as the leaves, showing commissural furrows. Commissural

furrows not continued on to the leafy shoot.   Midrib continued downwards as ribs on the leafy shoot.

Cuticle (only known in two species) showing elongated epidermal cells and stomata of an Equisetalean sort.

Cone (only known in four species) large, up to 7 cm. long, axis up to 7 mm. in diameter, consisting of distant alternate whorls of sterile bracts and sporangiophores. Bracts either like foliage leaves or modified, at least 7 mm. long, numerous. Sporangiophores twice branched (*P. australis*) or possibly branched in the stem cortex (*P. deliquescens*, *P. uluguruana*). Sporangia either few on small sporangiophore heads (*P. australis*) or many on large solid sporangiophore heads (*P. deliquescens*, *P. uluguruana*). Spores unknown.

The genus ranges from the Upper Carboniferous to the Wealden, and contains plants of quite a wide range of (vegetative) structure ; indeed, as has been noted by several authors, many species have been placed in *Phyllotheca* on rather slender evidence. This is especially the case with the Upper Carboniferous and post-Triassic species. The described cones also show considerable variation. The foregoing diagnosis is based upon *Phyllotheca australis*—the Type—and similar species of approximately the same age, and does not attempt to cover all the species that have been placed in *Phyllotheca*. A wide diagnosis of that sort would not serve to distinguish *Phyllotheca* from *Equisetites*, *Annularia* or *Neocalamites*.

Phyllotheca australis Brongniart.

Plate I, Text-figs. 1 and 2A.

1828 *Phyllotheca australis* Brongniart, p. 152.
1847 *Phyllotheca australis* Bgt. : McCoy, p. 156, pl. 11, fig. 1.
1847 *Phyllotheca ramosa* McCoy, pp. 156, 157, pl. 11, figs. 2, 3.
1847 *Phyllotheca hookeri* McCoy, p. 157, pl. 11, figs. 4–7.
1849 *Phyllotheca australis* Bgt. : Dana, p. 718, pl. 13, fig. 6.
1878 *Phyllotheca australis* Bgt. : Feistmantel, pp. 83–84, pl. 6, fig. 3, pl. 7, figs. 1, 2.   Not pl. 15, figs. 1, 2.
1878 *Phyllotheca ramosa* McCoy · Feistmantel, pp. 84–87.
1878 *Phyllotheca hookeri* McCoy : Feistmantel, pp. 84–87.
1890 *Phyllotheca australis* Bgt. : Feistmantel, pp. 79–81, pl. 14, figs. 2–4.   Not pl. 14, fig. 5.
1890 *Phyllotheca ramosa* McCoy : Feistmantel, p. 80.
1890 *Phyllotheca hookeri* McCoy : Feistmantel, p. 81.   (A reprint of 1878 ; no new material.)
1895 *Phyllotheca australis* Bgt. : Etheridge, p. 148, pl. 18, figs. 4, 5 only.
1898 *Phyllotheca australis* Bgt. : Seward, pp. 287–291 (part).
1902 *Phyllotheca australis* Bgt. : Arber, pp. 4, 14–17.   A re-examination of McCoy's (1847) material.
1905 *Phyllotheca australis* Bgt. : Arber, pp. 17–20, pl. 2, figs. ? 6, 7, 8.
1911 *Phyllotheca australis* Bgt. : Halle, p. 163, pl. 6, figs. 16, 17, 19, ? 15, ? 18, only.
1919 *Phyllotheca australis* Bgt. : Walkom, pp. 9, 12.   Discussion of the time range of *P. australis*.
1922 *Phyllotheca australis* Bgt. : Walkom, p. 5, pl. 1, fig. 1.
1923 *Phyllotheca australis* Bgt. : Seward and Walton, p. 318, pl. 21, fig. 16.
1932 *Phyllotheca australis* Bgt. : Du Toit, p. 374, pl. 40, figs. 3, 4.
1947 *Phyllotheca australis* Bgt. : Jones and de Jersey, p. 9.   Note supporting identifications of Walkom, 1915, 1925.

Doubtful records :

1903 *Phyllotheca australis* Bgt. : Chapman, pp. 320–321, pl. 28, figs. 5, 6.
1908 *Phyllotheca zeilleri* Etheridge : Seward, p. 82, pl. 8, figs. 2, 3.
1927 *Phyllotheca australis* Bgt. : Chapman, pp. 127, 128, pl. 11, fig. 16.
1927 *Phyllotheca indica* Bunbury : Chapman, pp. 125–127, pl. 10, figs. 4, 6, 9, pl. 11, fig. 15. Details not clear.   Specimens indistinguishable in figs.
1944 *Phyllotheca australis* Bgt. : Frenguelli, pp. 36–40, pls. 1–3.

The following are regarded as distinct.

1901 *Phyllotheca australis* Bgt. : Etheridge, p. 4, pl. 2, figs. 1–4.
1915 *Phyllotheca australis* Bgt. : Walkom, p. 32, pl. 1, fig. 5.
1925 *Phyllotheca australis* Bgt. : Walkom, p. 216, pl. 24, figs. 1–3.
1935 *Phyllotheca australis* Bgt. : Carpentier, p. 10, pl. 2, fig. 3.

For other early references, see Arber 1905.
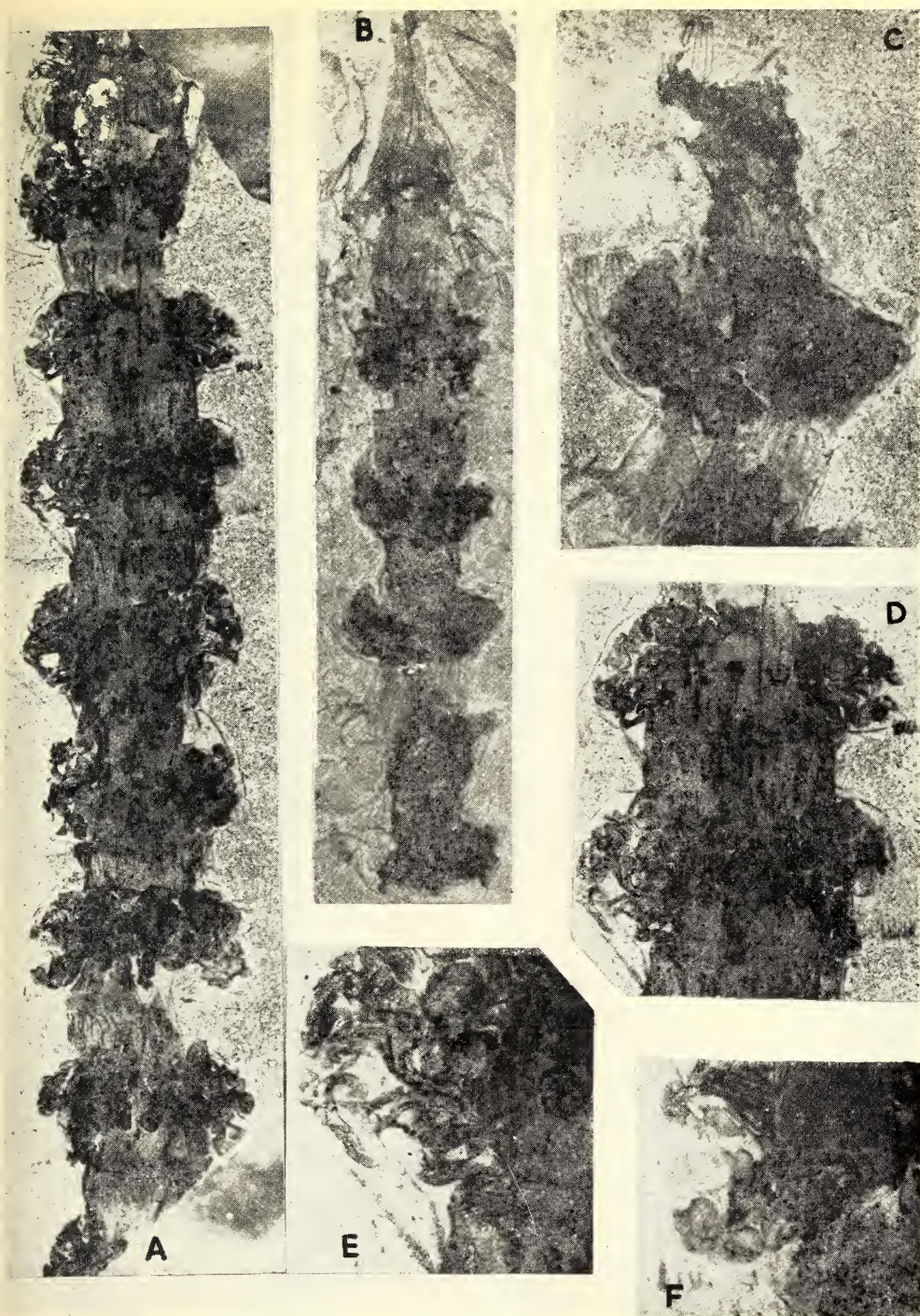
Cone of *Phyllotheca australis*.
(Photographs by the author.)

A. Incomplete cone, $\times 2$. V.30591a (part), British Museum.
B. Cone, showing bracts at the apex, and around the sporangiophores, $\times 2$. V.30592, British Museum.
C. Node (second from the bottom) showing cup-shaped bract whorls, $\times 3 \cdot 2$. V.30592, British Museum.
D. Third and fourth nodes from top, showing branched sporangiophores, and relics of bracts, $\times 3$. V.30591a, British Museum.
E. Part of fourth node from the top, showing delicate ultimate branches of the sporangiophore, $\times 6$. V.30591a, British Museum.
F. Part of seventh node from the top, showing two sporangia (at least) attached to a sporangiophore, $\times 6$. V.30591a, British Museum.
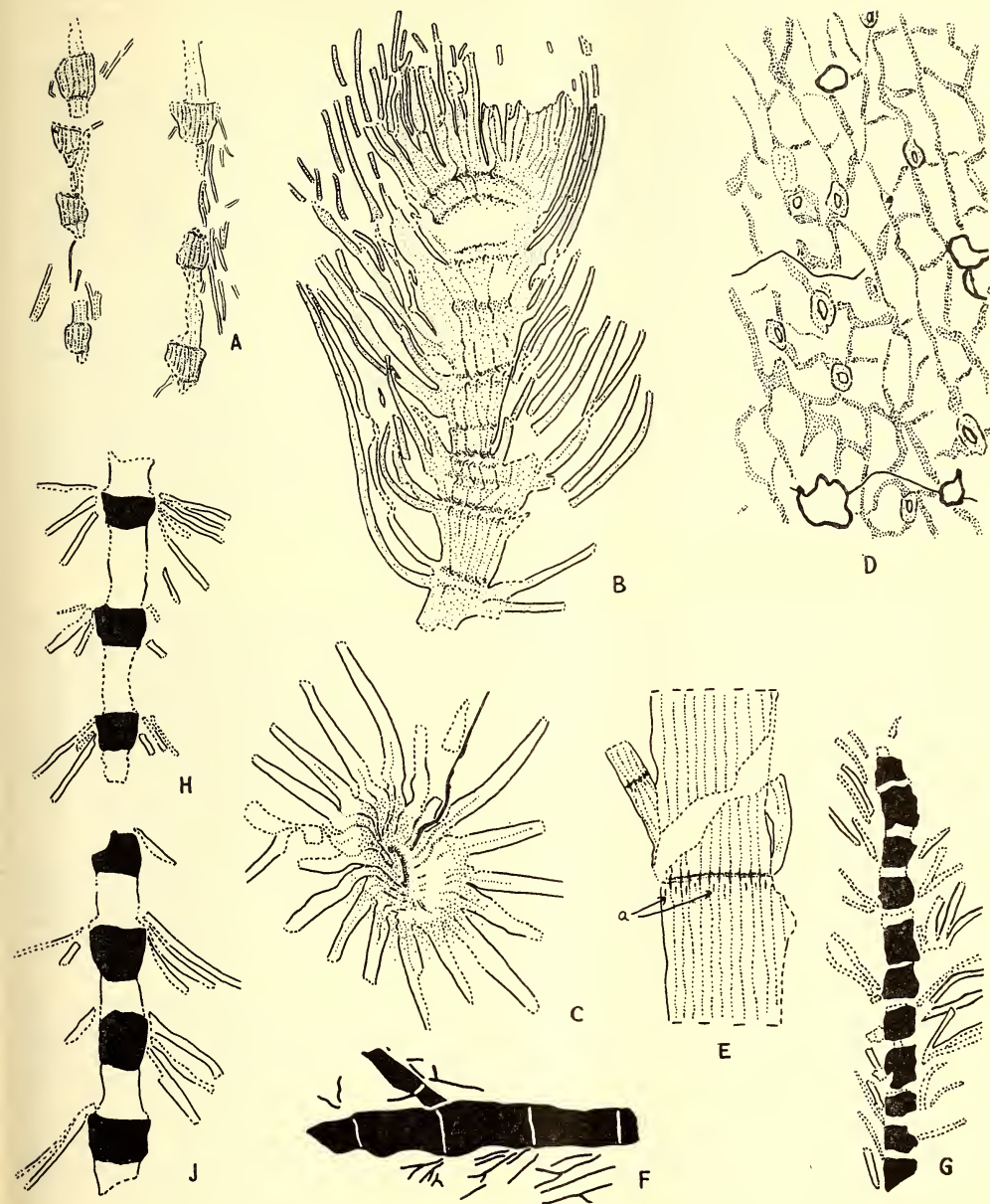
Fig. 1.—*Phyllotheca australis.*

A. Type specimen (stem on left), ×1. Drawn over photograph of part of Specimen 3388. Muséum National, Paris.
B. Shoot apex, ×5. V.24180, British Museum.
C. Detached sheath with leaves, ×4. L.13, Sedgwick Museum.
D. Epidermis from main stem, showing cell outlines and "pits", ×100. L.13, Sedgwick Museum.
E. Part of main stem with node and branch (*a*=tubercles), ×4. L.13, Sedgwick Museum.
F. Underground stem with branch and roots, ×0·5. L.13, Sedgwick Museum.
G, H, J. Leafy shoots to show variation in relative size and form of the leaf sheath, ×4. L.13, Sedgwick Museum.

F

Brongniart described *Phyllotheca australis* from specimens obtained from the Buckland Collection, and gave the locality as " Mines along the Hawkesbury River in New South Wales ".

However, Brongniart did not figure *Phyllotheca australis*, and apparently the Type never has been figured. Dr. E. Boureau, to whom I am greatly indebted for this assistance, located Brongniart's original material in the collections of the Muséum National d'Histoire Naturelle, Paris, and since he kindly sent three excellent photographs of Brongniart's material, I have selected one, the leafy stem shown in Text-figure 1, to designate as the Type. The photographs are labelled " *Phyllotheca australis* Brongniart. Hawkesbury River, prés le Port Jackson. Don de M. Buckland. Coll. Mus. Nat. Hist. nat., Paris 3388. Cliché Ed. Boureau.''

There are in the University Museum, Oxford, other blocks from the Buckland Collection (specimens G.W. Ia-Id, and G.W.2), also containing *Phyllotheca australis*, and almost certainly from the same locality, which hence are syn-types.

Other material described here is all stated to be from the Newcastle (New South Wales) Series (Permian), and is contained in the Clarke Collection (Sedgwick Museum, Cambridge) and the Tillyard and other collections in the Geology Department, British Museum (Natural History). The localities of these collections are different, to judge from the rock matrix.

Diagnosis (Emended).

Main stems, normally loosing leaves, 6–14 mm., usually 12 mm., wide at the node. Internode length 15–20 mm., usually about 20 mm. Width in the centre of the internode slightly ($0 \cdot 5$–$1 \cdot 0$ mm.) less than node. Node a transverse furrow, about $1 \cdot 0$ mm. wide. Whole stem longitudinally ribbed, about 12 ribs on visible side of specimen. On internode ribs broad, slightly convex, separated by narrow furrows. At node, and for $1 \cdot 5$ mm. on each side, ribs higher, angular, furrows rounded, becoming indefinite. Ribs continuous over several internodes. Epidermal features as on leaf-sheaths. Branches few.

Leafy shoots small, borne on main stems, or on branches, internode length about 10 mm. (3–12 mm.) node about $3 \cdot 0$ mm. wide ($1 \cdot 0$–$4 \cdot 0$). Exposed part of internode longitudinally ribbed, ribs small of semi-circular section, separated by wide flat-bottomed furrows. Ribs about one for every millimetre of width. Epidermal markings as on leaf-sheath.

Leaf-sheaths about $3 \cdot 0$ mm. long ($2 \cdot 0$–$4 \cdot 0$ mm.), covering from whole to just under half internode. Leaf-sheath showing ribs of same form as on internode and continuous with them, ribs also continued upwards as midrib of leaves. Furrows of same form as on internode. Epidermal markings, longitudinal cellular striæ about 30μ apart, with less distinct cross-walls about 40μ apart. Rows of pits running roughly longitudinally, about 16μ in diameter. When detached, leaf sheaths cup-shaped, ribs visible upon inner surface alternating with commissural furrows. Total leaves in a whorl 18–23 (usually 20).

Roots arising in whorls from underground stem of same character and dimensions as main stem.

Leaves flat, substance thin, margins entire. Width at base $0 \cdot 5$–$0 \cdot 75$ mm., evenly tapering, around 10 mm. long (3–15 mm.). Single fine midrib visible throughout whole length (except possibly apical $1 \cdot 0$ mm.), traceable on to sheath. No transverse striæ present.

Cuticle exceedingly delicate (obtained only from main stem) showing longitudinally elongated cells $56\mu \times 36\mu$, and elongated pits $16\mu \times 10\mu$ arranged in longitudinal rows.

Cone borne on an axis of similar internodal form as main leafless stem. Dimensions : internodal length, 7 mm.–10 mm. ; width, 5 mm.–7 mm. ; maintaining these dimensions to last (visible) node. Apex covered by at least two whorls of overlapping bracts, extending 11 mm. beyond last (visible) node. Node comprising two lateral furrows, 4 mm.–7 mm. apart, surface of stem between lateral furrows marked with longitudinal grooves or ribs, same in number as the sporangiophores and alternating with them. Bracts estimated at about 30 in a whorl, each bract about 10 mm. long and 0·25 mm.–0·5 mm. wide, arising from lower nodal furrow, and forming a sheath arching over the sporangiophores. Margins of bracts in lateral contact, or possibly united, to the apex ; apex truncated. Substance of bract delicate, midrib single.

Scars of sporangiophores round, 1·5 mm. in diameter, with one vascular trace. Sporangiophores about six in a whorl, twice branched, branching equal, basal portion of stalk 2 mm.–2·5 mm. long, 1·5 mm. in diameter, tapering, strongly wrinkled longitudinally : primary branches 2 mm.–3 mm. long, 0·5 mm.–0·75 mm. in diameter, not tapering, slightly wrinkled longitudinally ; secondary branches 1 mm.–2 mm. long, 0·2 mm. in diameter, not tapering or wrinkled, bearing few reflexed sporangia at their ends. Sporangia oval, 0·75 m. ×0·75 m., produced into a slight point, attached to sporangiophore by their upper and outer margins ; bearing faint marks of elongated cells. Spores unknown.

Description.

Specimen L. 13 from the Clarke Collection shows a main stem with a branch and leafy shoots all in organic connection. Upon the same block are the roots. Upon all the blocks examined, with one exception, only *Phyllotheca australis,* has been present ; thus it seems most likely that the roots belong to *P. australis.* The exception is a very small fragment of a *Glossopteris* leaf upon one of the blocks in the Buckland Collection (G.W.2).

Sundry authors (e.g. Arber, 1905 ; Du Toit, 1932 ; Seward, 1898) have included in *P. australis* stems of greater dimensions than a nodal width of 14 mm. usually upon evidence of association in the same collection. The present material suggests that the main stems and rhizomes were rather small, and I have no reason to believe that any of these large specimens belong to *P. australis.*

Two kinds of ribbing on the internode have been seen. The normal is as in Fig. I.E and the diagnosis. Another sort is seen in specimen L. 9 (Sedgwick Museum), which is the Type of *Phyllotheca hookeri* McCoy. The ribbing is normal at the nodes, but between is very much coarser, each of the coarse ribs representing two or more small ribs. This coarse ribbing is believed to be due to a wrinkling of the specimen after preservation.

Below the node on one or two specimens there are elongated tubercles, about 2·5 mm. long, alternating with the ribs, but not crossing the node. The tubercles are composed for the most part of solid carbon. Their nature is unknown.

It is not possible to say exactly where a branch is attached to the stem. In specimen L. 13 (Sedgwick Museum) the junction is apparently at the nodal furrow, and in specimen L. 8 (Sedgwick Museum) there is a round scar at a node which may be a branch scar. McCoy (1847, pl. 11) figures other branching stems from specimen L. 13, but I cannot agree with his interpretation of the various fragments. In any case branches were not numerous at each node.

In Text-figure 1, B, a sterile stem apex is shown. The uppermost four internodes are completely covered by the leaf-sheath, and in the leaves covering the apex proper some midribs are visible, suggesting that tissue differentiation

was well advanced. Several stem apices are present in the material, and all show some leaves in the first visible whorl with midribs.

The roots are $0 \cdot 75$–$1 \cdot 0$ m. wide, sparingly branched, with strong longitudinal striæ, not tapering perceptibly, and they show no epidermal features such as hairs. Their branching may be dichotomous, for just before a division some of the longitudinal striæ divide, and each branch has nearly equal numbers of striæ. The two branches are of equal size. Just before division the parent root swells slightly. The roots may be distinguished from leaves by (a) their greater size, (b) the striæ, which are stronger and fewer, (c) their branching, and (d) their lack of taper. The number in a whorl is not known exactly ; it appears to be about eight. The nature of the striæ is not known, they do not much resemble vascular traces for they are in places minutely sinuous and irregular in outline.

The substance of the leaf-sheath is thin, except in the ridges alternating with the midribs. Many leaf sheaths are preserved at right angles to the bedding, so that the whole leaf-sheath is visible. These ridges are minutely sinuous in places, and are irregular in thickness and form ; they also run out along the leaf-margins for about $1 \cdot 0$ mm. Similar ridges have been figured before, in particular by Du Toit, 1932. Their significance is discussed below.

Despite many efforts a cuticle could not be obtained by normal maceration with $HNO_3 + NaClO_3$. The coaly material on a main stem of specimen L. 13 was very thin and partially translucent, and part was removed as a collodion " pull " and bleached with an acidified solution of sodium chlorite. By this means the outlines of cells (probably epidermal) were discovered. The pits often had very fine wavy lines radiating from them ; but the nature of the pits and these lines is obscure. Cell outlines were not visible in material from the leaves.

Interpretation.

It seems certain that the stems did not contain extensive woody tissue, for after bleaching only one layer of cells could be distinguished while the internodal ribs appeared as small dark strands, the whole of the rest of the tissues being only a thin brown film. The internodal ribs are probably cortical fibres and vascular tissue. Chapman (1927, plate XI, fig. 15) has figured nodal diaphragms, but their details cannot clearly be made out, and I believe they may belong to another plant. Certainly in the material to hand there is no sign of diaphragms either preserved in place, rotated, or even associated with *Phyllotheca australis*.

In leafy shoots the continuity of the midrib and the longitudinal ribs on the internode and leaf-sheath makes it certain that the ribs include vascular tissue. In that case the bundles were small, and apart from them the stem appears to have lacked lignified tissue.

There is no overlap between the characters of leafless and leafy shoots, even when in organic connection. This suggests that the plant had main stems, always leafless (or else with some sort of leaves that soon were shed) and leafy shoots arising from buds on the main stems. The close correspondence in size and features of the main stems bearing roots and of others bearing leafy shoots I regard as good evidence that in the present material we have (at least nearly) the maximum stem dimensions ; further, the evidence strongly suggests that increase of stem width by secondary thickening was, at best, only slight. For these reasons I have rejected (see above) identifications of large stems as *Phyllotheca australis* ; usually pith-casts showing evidence of considerable xylem masses.

Du Toit (1932) speaks of veins between the midribs, and extending to the margin of the leaf-sheath. In calling these " veins " it is believed that he was

misled. The " veins " are here regarded as commissural furrows, which appear as ridges upon the inside of the sheath. This is because :

(a) Their form is unlike that of the midrib (see above) ; and

(b) the " veins " fork at the edge of the sheath and run up the extreme margins of the leaves.

This behaviour seems unusual for vascular bundles in Equisetales.

On this view the " veins " at the leaf margins in fact represent a thickened or inrolled leaf margin.

The form of the leaf-sheath has been the subject of some disagreement ; it is spoken of as adpressed (e.g. Brongniart, 1828 ; Arber, 1905) or as spreading (e.g. McCoy, 1847 ; Du Toit, 1932). Here it is suggested its form varies with the size (and age ?) of the shoot. When young the sheath covers all, or nearly all, the internode, is adpressed, and the leaves depart at about 45° to the stem ; later the angle of departure of the leaves increases till they become reflexed, the sheath bells out from the stem and covers proportionally less of the internode. Some data upon this are presented below.

TABLE I.

To Illustrate the Changes in Leaf Sheath Length and Form with Increasing Stem Width.
(The figures are averages of several measurements wherever possible.)

Material.	Stem Width in Millimetres at		Length of Sheath.	(Exposed) Length of Internode.
	Sheath Base.	Sheath Top.		
Clarke Coll. L.13	1·0	1·0	2·0	1·5
Tillyard Coll. (B.M. No. V.24180) ..	2·0	2·2	3·0	2·0
Clarke Coll. L.13	2·0	2·5	3·0	2·5
Clarke Coll. L.13	2·2	3·0	3·2	3·0
Buckland Coll. G.W.2	2·5	3·0	3·0	5·0
Clarke Coll. L.13	2·5	3·0	3·0	4·0
Buckland Coll. G.W.2	3·0	4·0	3·0	4·0
Tillyard Coll. (B.M. No. V.24180) ..	3·0	3·9	2·0	3·0
Clarke Coll. L.13	3·0	3·5	2·75	3·0
Buckland Coll. G.W.1	4·0	5·0	4·0	9·0

The fructifications consist of two specimens from the Tillyard Collection, a part and counterpart (V.30591) and one other (V.30592). In this last it was possible to uncover the apex. There is hardly any plant matter left, the fossils being brown stains on the rock, which shows, however, considerable relief, due, it is believed, to the form of the fossil before oxidation of the coaly matter.

The cones are ascribed to *Phyllotheca australis* for two reasons. Incidentally the obscure cone figured by McCoy (1847) also very probably belonged to *P. australis*.

(1) The internodal structure and dimensions (except internodal length) are as in *P. australis* ; in particular the shape of the longitudinal ribbing.

(2) The specimens are closely associated with several stems and leafy shoots which certainly belong to *P. australis*, and no other plant is present on the blocks.

The branching of the sporangiophores is clearly seen at a few points (Plate I, figs. D, E) and even when obscured it is obvious that the final branches are far more numerous than the scars on the axis. As far as I know they branch twice,

the first time longitudinally, the second time probably in the other plane.   At each branch the size of the stalk is much reduced.

The ultimate branches, which are only $0 \cdot 2$ mm. in diameter, end in minute and delicate heads, not large peltate discs as in some Equisetales.   Some of these heads show two reflexed sporangia, and it is possible that their number is no more.   The sporangia were certainly not numerous.

The bracts are obvious at almost all the nodes, usually joined in groups of two or three, and more spread out from the axis in the lower (probably older) nodes.   Thus they would appear to have enclosed the sporangiophore whorls at first, later spreading and exposing them.

Since the internodal structure and dimensions (except for internode length) are so similar to the main (leafless) stem, I suggest that the cone was terminal on a stem bearing branches or leafy shoots below.

Comparisons.

McCoy (1847) divided *Phyllotheca australis* Brongniart into three, *P. australis* sensu McCoy, *P. ramosa* McCoy and *P. hookeri* McCoy.   The only distinguishing feature of *P. ramosa* that is at all plain is its branching habit, which alone cannot be used as a specific character.   The differences between *P. australis* (taken to include *P. ramosa*) and *P. hookeri* are as follows :

Phyllotheca australis.	*Phyllotheca hookeri.*
(1) Leaves thin with fine midrib.	(1) Leaves thick with prominent midrib.
(2) Sheath adpressed.	(2) Sheath loose.
(3) Stem finely ribbed.	(3) Stem coarsely ribbed.

Feistmantel (1878, 1890) expressed the view that these features could not be used to separate McCoy's species ; and Arber (1902) recombined all three species into *Phyllotheca australis* Brongniart.

Examination of McCoy's Type specimens of *P. ramosa* and *P. hookeri* confirms this view.   The leaves on one individual vary more widely than between *P. australis* and *P. hookeri*.   This difference on one individual seems to depend on the angle of the leaf relative to the bedding planes.   As has been noted above, the leaf-sheath form depends on the size of the stem.   The difference in ribbing has been noted, and if due, as suggested, to the preservation, it is useless as a taxonomic character.

A comparison with *Phyllotheca indica* and with other species of *Phyllotheca* is given below.

Time Range.

The great majority of records of *Phyllotheca australis* are from the Newcastle Series (Permian).   Other records are from the Beaufort Series, South Africa (Permian passing into Trias), and from rocks correlated with the Indian Gondwana Series (Carboniferous and Permian) in the Falkland Islands.   Hirmer (1927) states that it has been found in Permo-Carboniferous rocks of Brazil, but I have not been able to find any record of *P. australis* from rocks of that age in South America, though very similar species have been found.

Specimens have been attributed to *P. australis* from Triassic rocks (Arber, 1902 ; Carpentier, 1935 ; Chapman, 1903, 1927 ; Walkom, 1915, 1925 ; and Frenguelli, 1944) but all are based on ill characterized specimens (the locality of Arber's material is not quite certain) and some are almost certainly distinct. Frenguelli (1944) evidently had abundant material but called two very different looking plants *P. australis* (cf. Feistmantel, 1890).   In addition he notes that the

longitudinal ribs alternate, which they do not do in any other material of *P. australis*, the leaves are fewer and in his figures they look much more robust than is normal ; the main stems are thinner than those of any material or figures I have been able to examine. I regard this record as doubtful.

There is, however, one block in the British Museum (V.24522) stated to be of Triassic age, from Freshwater, near Manly, New South Wales, with poorly preserved remains, probably of *Phyllotheca australis*.

It would seem better to regard *P. australis* as a Permian species ; if it ranges into the Trias this has yet to be conclusively demonstrated.

Normal Species of the Genus.
(1) **Phyllotheca indica** Bunbury.
Text-fig. 2, B-F.

1861   *Phyllotheca indica* Bunbury, p. 325, pl. X, figs. 2–9 except fig. 6, not pl. XI, fig. 1. Diagnosis and description.
?1876 *Phyllotheca indica* Bunb. : Feistmantel, p. 218. No figure.
1880   *Phyllotheca indica* Bunb. : Feistmantel, p. 67, pl. XIIA, figs. 3–9.
1893   *Phyllotheca indica* Bunb. : Oldham, pl. opposite p. 162. Figure reproduced from Feistmantel, 1880.
1898   *Phyllotheca indica* Bunb. : Seward, pp. 287–289, fig. 68c. Discussion of relationship of *P. indica* and *P. australis*.
1905   *Phyllotheca indica* Bunb. : Arber, p. 21, fig. 6. Discussion of relationship of *P. indica* and *P. australis*, fig. 6, after Feistmantel (1880).

The following are regarded as distinct :

1927 *Phyllotheca indica* Chapman (non Bunbury), p. 125, pl. X, figs. 4, 6, 9.
1932 *Phyllotheca australis* (=*Phyllotheca indica*) Du Toit (non Bunbury), p. 374, pl. XL, figs. 3, 4.

Bunbury obtained his material from a collection made by Hislop and Hunter at Bárátwádá, Nagpur from a horizon in the upper part of the Gondwana Series (Permo-Carboniferous). The material of the present description is Bunbury's type material, and specimens from the Hislop and Hunter Collection not hitherto described. All the specimens are in the Geology Department, British Museum (Natural History).

Diagnosis (Emended).

Main stems without leaves, internodal length 13–25 mm., usually about 20 mm. Nodal width 5–15 mm., usually about 13 mm. Internode surface ribbed longitudinally, ribs convex somewhat flattened, furrows between narrow. Ribs becoming angular but lower at the node. Ribs cross node, are continuous over several nodes and internodes. Node a simple transverse furrow about 1·0 mm. wide. Epidermal features as for leaves.

Leafy shoots ; width at base of sheath about 3·0 mm. (2·2–4·0 mm.), longitudinally ribbed, ribs fine, convex, not truly semi-circular, separated by wide flat-bottomed furrows. Epidermal features not seen.

Leaf-sheath about 3·5 mm. long (2·0–7·0 mm.), width at top 2·75 to 5·0 mm. Ribbed as internode, ribs continuous with those of internode, and upwards into midrib. When preserved isolated showing commissural furrows upon inside. Leaves 18–22 in a whorl. Epidermal features as on leaves. Leaves 0·5–0·75 mm. wide at base, up to 30 mm. long (apical region not known) not tapering in that length. Single midrib visible for whole known length of leaves. Epidermal features, longitudinal cellular striæ about 65µ apart, joined by indistinct cross-walls.

Description.

The material consists of about ten leafy shoots and three larger stems like those of *Phyllotheca australis*. The specimens are completely flattened, and the original substance has been almost entirely replaced by ferric oxide, so we have
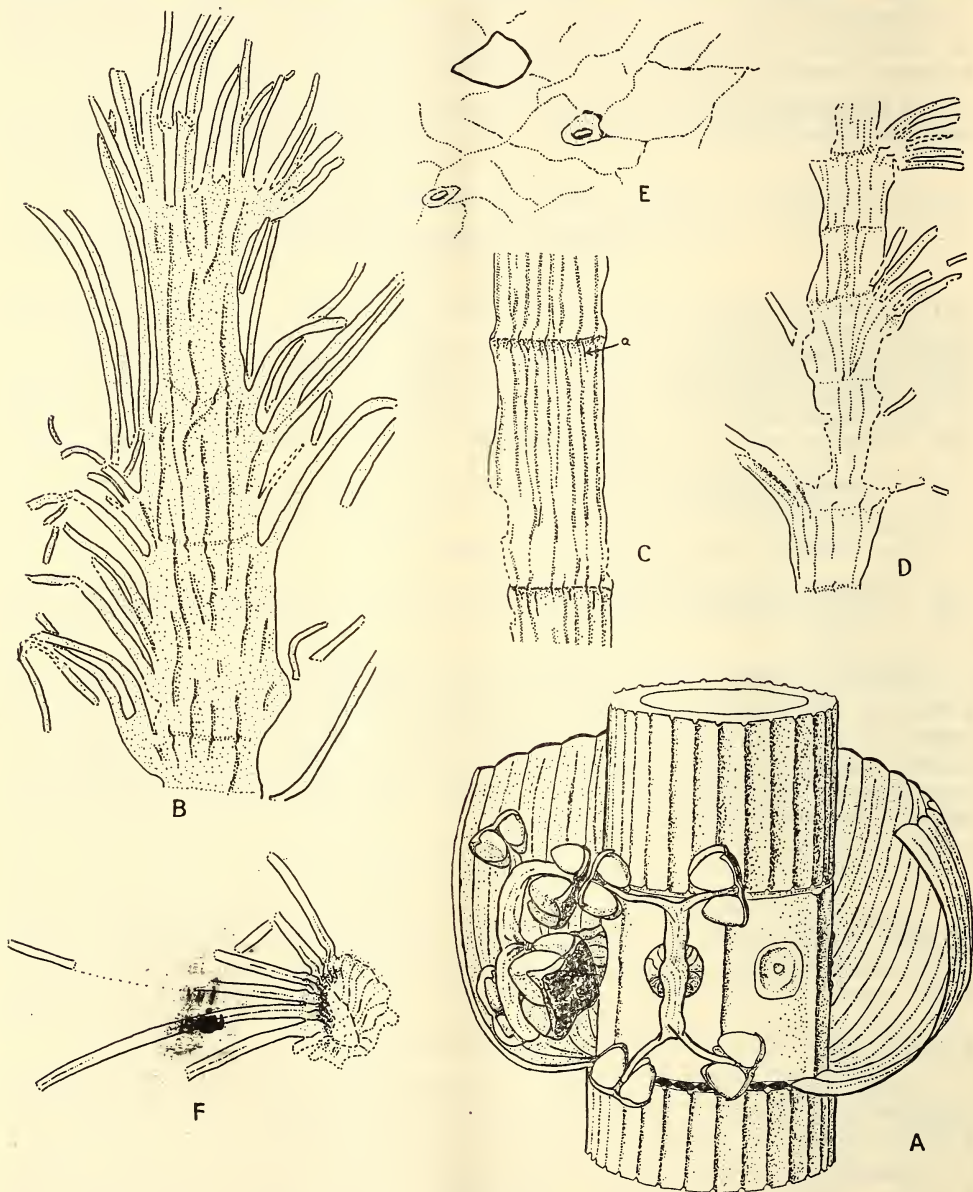
Fig. 2.—A, *Phyllotheca australis*, and B–F, *Phyllotheca indica*.
A. Reconstruction of a node of the cone.
B. Shoot apex, ×5. V.19607, British Museum.
C. Part of main stem (a=tubercles), ×4. V.19606, British Museum.
D. Leafy shoot, some leaves attached, ×4. V.19641, British Museum.
E. Probable prints of epidermal cells and " pits ", on main stem, ×100. V.19606, British Museum.
F. Detached leaf sheath with leaves, ×4. V.19637c, British Museum.

only lighter and darker brown colours to compare with distinct, though low, relief in *P. australis*. In places epidermal features can be seen.

Large strongly ribbed stems (often pith-casts) are regarded as distinct from *P. indica*.

In the stem apex the topmost leaves have midribs, hence were presumably already largely differentiated. There is also a suggestion in these short young leaves of a pointed tip.

There are elongated tubercles below the node in one of the large stems, but they are indistinct. It is possible that this is due to the mode of preservation, i.e. in ferric oxide. The elongated tubercles (which are largely formed of coal) have been replaced by ferric oxide but with some wasting, so becoming smaller and less distinct.

There is only one detached leaf-sheath in the material, and it has 21 leaves in a whorl. The midrib shows plainly along certain of the leaves, and is continuous on to the sheath. Commissural furrows are present between the veins as in *P. australis*. The leaves do not taper. The longest leaves are not in contact with a stem, but are very closely associated. In these also the midrib is visible for the whole preserved length, and the leaves do not taper.

The cuticle as such could not be prepared. The ferric oxide was soluble in hot oxalic acid, but then the fragile cuticle disintegrated. Celloidin " pulls ", taken off the surface of specimens in places where epidermal features could be seen, gave in several cases faint but distinct impressions of epidermal cells. The cells are longitudinally elongated, measuring $80\mu \times 90\mu$. There are slightly elongated pits, apparently in longitudinal rows, with their long axes parallel with the long axes of the epidermal cells. They measured $30\mu \times 20\mu$.

The leaf-sheath varies in form, like *P. australis*, with the size of the stem. There is not enough material of either to decide whether this variation is quantitatively the same in the two species : qualitatively the variation is very similar.

TABLE II.
To Illustrate the Changes in Leaf Sheath Length and Form with Increasing Stem Width.
(The figures are averages of several measurements wherever possible.)

Material.	Stem Width in Millimetres at		Length of Sheath.	Exposed Length of Internode.
	Sheath Base.	Sheath Top.		
B.M. No. V.19638	2·2	2·75	4·1	3·0
B.M. No. V.19638	2·6	3·0	4·2	3·0
B.M. No. V.19641	3·5	4·0	4·0	6·1
B.M. No. V.19648	4·0	5·0	6·0	8·0
B.M. No. V.19638	4·0	5·1	7·0	11·0

The roots and cone of *Phyllotheca indica* are unknown.

Comparisons (on Vegetative Characters).

Phyllotheca indica has been regarded by Seward (1898) followed by Du Toit (1932) as identical with *Phyllotheca australis*; others, e.g. Arber (1905) and Chapman (1927), have kept them distinct. Though similar, I believe *P. australis* and *P. indica* should be kept as separate species. I regard the following differences as important.

Phyllotheca australis.	*Phyllotheca indica.*
(1) Leaves commonly 10 mm. long (extremes 3–15 mm.).	(1) Leaves commonly 25 mm. long (extremes 6–30 mm.).
(2) Leaves tapering evenly to a pointed apex.	(2) Leaves not tapering at all till near the end.

There are no reliable differences in the characters of the stem and leaf sheath. There is a suggestion that *P. australis* has smaller epidermal cells and " pits " ($50\mu \times 36\mu$ and $10\mu \times 16\mu$) as against *P. indica* ($80\mu \times 90\mu$ and $30\mu \times 20\mu$).

Phyllotheca indica and *P. australis* taken together may be compared with *Phyllotheca deliquescens* (Goeppert) Schmalhausen (1879), and see Arber (1905). The stem of *P. deliquescens* is more solid and strongly ribbed, sometimes giving nearly round pith-casts like *Calamites*, and branches are given off in whorls at the node. The leaf-sheath nearly always seems to cover almost all the internode, even in large leafy shoots. The leaves resemble those of *P. indica* in that they are long and do not taper till near the end. There are apparently but 10–15 in a whorl in Indian material. The cones of *P. deliquescens* and *P. australis* differ considerably and will be compared later.

There are several other species similar to *P. australis* and *P. indica*, from the Permo-Carboniferous, but they are all little known.

(1) *Phyllotheca muelleriana* White (1908). The leaves of this species are stated to be inrolled at the tip, but this is far from clear in the figures. The leaves are at least as long as the sheath, and are not evenly tapering. It compares with *P. indica*.

(2) *Phyllotheca leptophylla* Kurtz (1921). (From figures only.) In dimensions and in having tapering leaves this species compares with *P. australis*. But even in large leafy shoots the leaves do not spread, there are about 30 leaves in a whorl, and the ribbing on the stem may be angular.

(3) *Phyllotheca griesbachii* Zeiller (1892), see also White (1908). Zeiller's material was a single specimen, and as Zeiller notes, rather imperfect. The figure is exceedingly like *P. indica*, but since the evidence is so scanty it seems better not to unite the two species. White's figured material differs somewhat from *P. indica* and from *P. griesbachii* Zeiller. There are about 30 leaves in a whorl, and the sheath is said to be short.

(4) *Phyllotheca zeilleri* R. Etheridge Jun. (1892), see also Seward (1908). Seward's material is, as he remarks, very similar indeed to *P. australis* and I believe Du Toit (1932) was correct in uniting the two. However, to judge solely from the figures Etheridge's material is different, and much more like *P. indica*. But it has about 30 leaves in a whorl, and the leaves are very thin and needle-like. It is not entirely clear that the leaf-sheath is very short, as Etheridge states.

Time Range.

The only records of *Phyllotheca indica* which seem to be trustworthy are from the Permian of India. The species has been confused with *P. australis*, and has been recorded from Australia, but the specimens figured are not at all convincing. In the absence of fairly well preserved leaves the two species would be nearly indistinguishable.

(2) **Phyllotheca sahnii** Saksena.
Text-fig. 3, A, B.

1952 *Phyllotheca sahnii* Saksena, pp. 409–412, pls. 1, 2.

The material which Saksena had did not show any leaves, they had broken off ; also the nature of certain striæ upon the leaf-sheath was left open. The present material, though fragmentary, does show leaves and striæ. A cuticle,

about which further information is desirable, could not be prepared.   The age
of the material is Upper Permian, from the Newcastle Series, thus approximately
contemporary with Saksena's ; localized, " Sugarloaf Pit, Towoomba, near New-
castle ". It is part of the Tillyard Collection, British Museum, numbered V.24439.
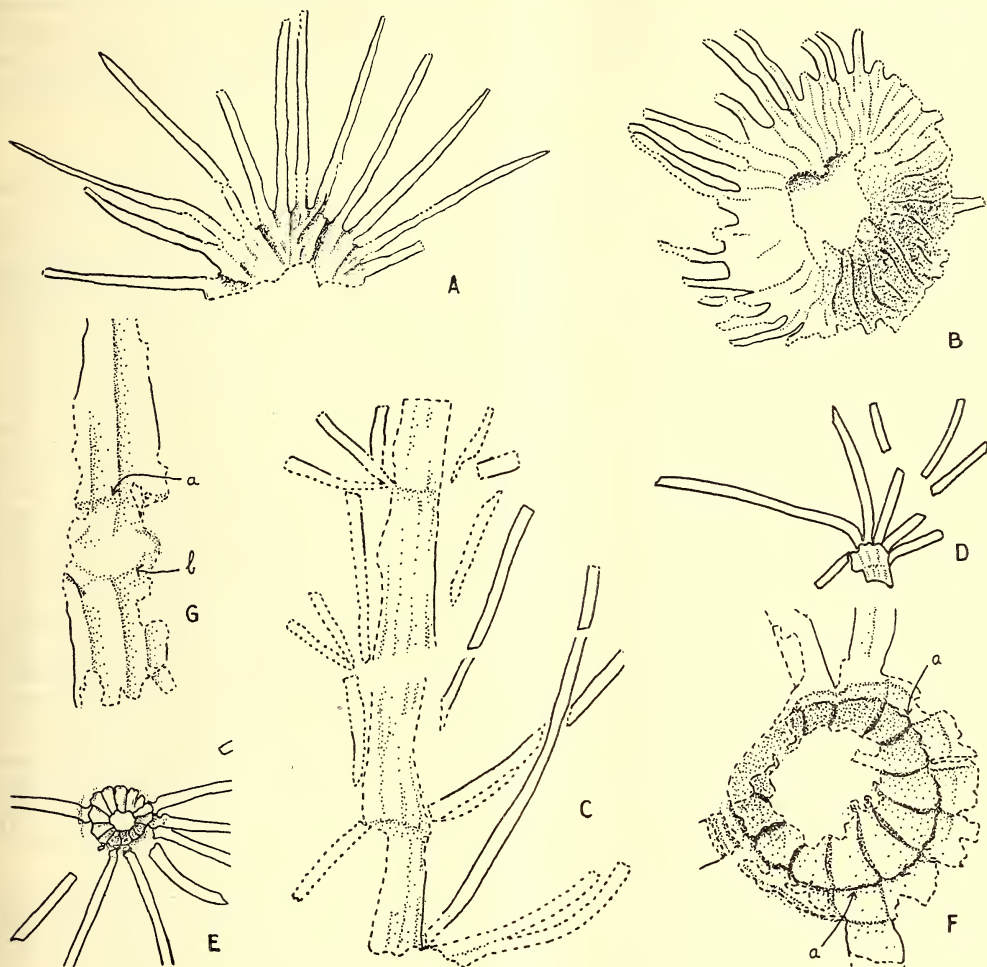
Fig. 3.—A, B, *Phyllotheca sahnii* ; C–G, *Phyllotheca brookvalensis*.
A. Part of leaf sheath showing pointed leaves, × 2. V.24439, British Museum.
B. Leaf sheath, showing hole in (presumed) position of stem, and nearly complete leaf whorl, × 2.
    V.24439, British Museum.
C. Stem with leaves, but no coaly matter, × 2. V.31858, British Museum.
D. Nodal region with leaves attached, before transferring, × 1. V.31857, British Museum.
E. Node with leaves, viewed from above, before transferring, × 1. V.31859, British Museum.
F. Transfer of same node (*a* = upper nodal furrow), × 5. V.31859, British Museum.
G. Transfer of nodal region of stem, × 6. V.31861*b*, British Museum.

Diagnosis Emended, partly from Saksena (1952).

Stems faintly ribbed longitudinally, swollen at the nodes.   Leaf-sheath
narrow amplexicaul at the base, spreading above into an open saucer-like disc,
at least 15 mm. in diameter, consisting of not less than 22 segments.   Com-
missural furrows around 0·25 mm. wide, ending at margin of the sheath, giving
space 0·25 mm. wide between each leaf at its point of insertion.   Segments
slightly concave on adaxial side, convex on abaxial.   Leaves as many as segments

(between 20 and 32), about 15 mm. long, between 0·75 mm. and 1·25 mm. wide at the base, spreading straight out from the sheath evenly, tapering to a point. Leaves slightly concave adaxially, midrib visible and continued on to the sheath on the adaxial side, midrib hardly visible on the abaxial side. Leaf margins thick, forming a ridge on the adaxial side, entire. Leaves showing faint cellular striæ about 50μ apart, with indistinct cross walls about 70μ apart. Fine cellular striæ on the sheath, running longitudinally at around 20° to the veins on abaxial side, nearly parallel to veins on the adaxial side, with very indistinct cross walls.

Description.

One complete and three parts of leaf-sheaths are shown, they all have leaves attached for part of the margin. The sheaths measure 17 mm., 18 mm., 11 mm. and 20 mm. in circumference (the last three are estimates), while the number of leaves is 30, 22 (in about two-thirds of the circumference), 12 (in over half the circumference), 12 (in half the circumference). Not many leaves are complete to the end, but all show some tapering. In two fairly complete specimens there is a hole about 6 mm. in diameter, presumably marking the position of the stem.

The commissural furrow is visible upon both sides of the sheath, but chiefly upon the adaxial side, where it stands out as a ridge above the segments of the sheath, which are themselves somewhat concave. On the abaxial side the commissural furrow appears as a furrow. The midrib appears as a ridge upon the abaxial side, but is hardly visible at all on the adaxial side.

Concerning the striæ upon the leaf-sheath, in the present material they are most indistinct, but they appear exactly like those on the leaf, which I regard, by analogy with other species of *Phyllotheca*, as most probably cell walls. Neither on leaf-sheaths upon the rock nor in transfer are the striæ at all like strands of coaly matter which lignified tissue is commonly preserved as. I prefer to regard them as cell walls, perhaps with some cell inclusions similar to those found by Walton (1936) in *Annularia*, and not as lignified tissue which Saksena thinks possible (though also referring to Walton 1936). Upon this view their radiating appearance is easily explained since the whole sheath is radially symmetrical.

The angle which the striæ make with the veins varies on the two sides of the sheath. This, taken with evidence from the appearance of the leaf segments and midrib may be due to the tissue of the sheath having been thick, that is that the two sides of the sheath were not parallel, since the more convex the segments the greater the angle at which the striæ would diverge from the veins.

The thickened margin of the leaf is a feature which varies somewhat in form though it is always present. On some leaves it looks like a commissural · flange, in others a solid rounded ridge (the majority), in others again a flange, but pointing in different directions, giving the leaf section the shape of a Z on its side. This variability seems to rule out the possibility that we are dealing with a commissural flange of the sort seen in *Equisetites*. The concave form of the leaf, and the thick margin (seen especially well in transfer) seem to indicate that the leaf was fleshy with an inrolled margin (cf. Walton 1936), with the midrib perhaps forming a projecting ridge on the adaxial side, since it is hardly visible on the abaxial.

Comparisons.

The Australian material agrees with the Indian as follows :

Australian material.	*Indian material.*
(1) Sheath 11 mm. - 20 mm. in diameter.	(1) Sheath 15 mm. in diameter.
(2) 20–30 segments on the sheath (count of 30, estimates of 20–30).	(2) 21–23 segments on the (counts).
(3) Stems 6 mm. in diameter.	(3) Stems 5–7 mm. in diameter.

There may be a difference in the cellular sculpture of the sheath but I suspect it is merely the result of different preservation. The Indian material shows rather distinct striæ at an angle of 60° to the veins. The Australian material shows indistinct striæ and those that were seen were some at about 20° and some at about 45° to the veins even upon the same specimen. The Australian ones are too imperfectly known to be used for comparison.

Saksena compared *P. sahnii* and *P. etheridgei* in some detail. The important points now seem to be :

(1) *P. sahnii* has tapering leaves 15 mm. long, while *P. etheridgei* has only short free teeth, not much above 1·0 mm. long.

(2) *P. sahnii* has stomata 16μ×32μ, and *P. etheridgei* has stomata 9μ×12μ.

Phyllotheca sahnii resembles *Phyllotheca australis* in having evenly tapering leaves and an inrolled leaf margin, but differs in the form of the sheath, the length of the leaves and in the length of the inrolled margin of the leaf.

SPECIES DOUBTFULLY ASSIGNED TO *Phyllotheca*.
(1) **Phyllotheca brookvalensis** sp. nov.
Text-figs. 4, A-C ; 5, A, B.

1915   *Neocalamites hœrensis* Walkom (non Halle) p. 33, Pl. II, fig. 1.
1947   *Neocalamites hœrensis* Jones & de Jersey, p. 10.
        Short note (no figure) on Walkom's material.

The material containing *Phyllotheca brookvalensis* comes from Beacon Hill quarry, Brookvale, near Sydney, New South Wales, and comprises part of the Tillyard Collection in the Department of Geology, British Museum. The specimens show several nodes, compressed at various angles to the position of growth, and two stems with attached leaves, one small with the coaly matter remaining, the other large with hardly any coal left. The rock in which they are preserved is a grey-red shale, and rather unfossiliferous. The age of the Brookvale deposits (the Hawkesbury Sandstone) is middle Triassic.

Diagnosis.

Stems with nodes 2·0-5·0 mm. wide, internode longitudinally ribbed at intervals of 1·0-1·5 mm.   Ribs stand 0·5 mm. above the furrows, angular and with flat sides extending to angular furrows. Surface showing longitudinal cellular striæ about 45μ apart.   Ribs of internode continued on to next internode without regular alternation. Node somewhat expanded, surface (in absence of leaves) forming a transverse depression 1·5-3·0 mm. across, bounded by two narrow transverse ridges, the internodal ribs extending into the transverse ridges but not visibly crossing the transverse depression. Surface of depression without cellular striæ, irregularly raised in lumps suggesting broken cells.

Isolated leafy nodes expanded considerably above, surface showing two transverse furrows, one where the leaves depart, the other 2–3 mm. lower. Surface of node showing strong decurrent ridges continuing leaves downwards, showing cellular striæ on their surface. Decurrent ridges convex not angular, interrupted by the two transverse furrows, but then continued on to internode below.   Node bearing 10–14 leaves.

Leaves 0·75-1·25 mm. wide at base and over much of their length, not tapering.   Length at least 65 mm. (apical region unknown).   Midrib clearly marked over most of leaf, but becoming somewhat broader and ill defined near

attachment. Leaf substance thick, margin flat, entire ; transverse striations not visible in lamina, leaf showing longitudinal cellular striæ around 45μ apart.

Cuticle exceedingly delicate (obtained only from leaf) showing elongated cells 65μ×45μ.
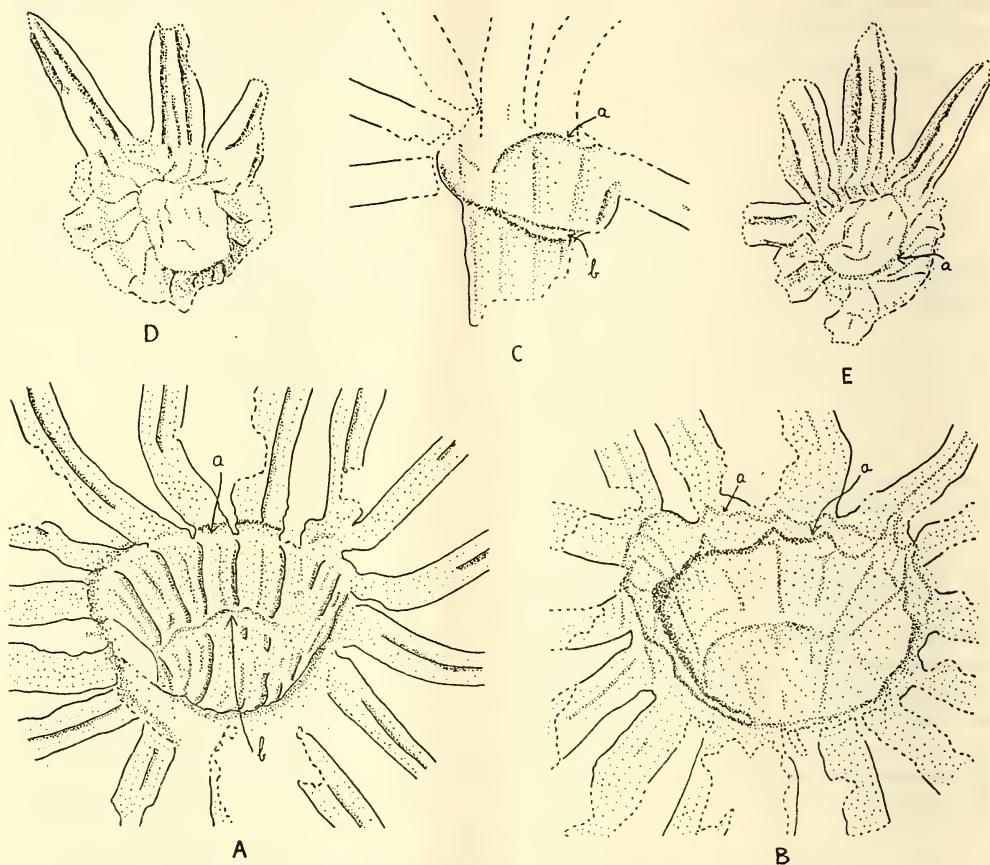
Fig. 4.—A–C, *Phyllotheca brookvalensis* ; D, E, *Equisetites minuta*.

A. Nodal region, with leaves attached, before transferring, ×5. V.31862a, British Museum.
B. Transfer of same node, ×5. V.31862a, British Museum.
C. Transfer of nodal region and of leaves, ×5. V.31857, British Museum.
    (In foregoing, a=upper nodal furrow, b=lower nodal furrow.)
D. Node and leaves, seen from below, ×2. V.15662 (681), British Museum.
E. Node and leaves, seen from above, ×2. V.15662 (682), British Museum. (a=shelf believed to represent position of attachment of next internode above.)

Description.

The specimens described as *Phyllotheca brookvalensis* are leafy stems and isolated leafy nodes. The stems are preserved without an infilling of mud to give the internal features, and the external features, i.e. longitudinal ribs, are only clear in specimen V.31860, where the coaly substance is still present. The ribs seen on one surface are not the same as those on the back and exposed in transfer. However, in some nodes (specimens V.31859 and V.31862a) the internal features of the stem may be seen in transfers.

The nodal structure is shown in three well-preserved detached leafy nodes (specimens V.31859, V.31857 and V.31862a) and in all the upper and lower nodal

furrows are clearly visible, and in transfer show as ridges. The ridge representing, in transfer, the upper nodal furrow is jagged (Text-fig. 4, B) and is regarded as the broken off remains of the internode above, while the distance between the features a,a in Text-fig. 4, B, is thought to be a very oblique section through the tissues of the stem. The small points are perhaps remains of vascular tissue. The ridge representing in transfer the lower nodal furrows is not jagged, but more rounded. Specimen V.31862a is regarded as being broken off at the lower nodal furrow. The furrows between the longitudinal ribs upon these leafy nodes are narrower than on the internodes.

There is nowhere any sign of a feature that could be called a leaf scar.

In specimens V.31859 and V.31860 those leaves which might be expected to be compressed at right angles to the bedding-planes are slightly contracted towards their point of departure, in one case the decrease in width is by $0 \cdot 15$ mm.

Around the leaf bases there is a slight trench, about $2 \cdot 0$ mm. across, quite distinct from the upper nodal furrow. This trench is very indistinct, if present at all, in transfer. In this trench the midribs are not visible ; they broaden and die away at the rim of the trench. No complete leaf has been found, the longest seen (65 mm.) was detached but closely associated with a node in specimen V.31857.

The cuticle was difficult to prepare, for in addition to its fragility the coaly matter broke up on maceration into minute parallelograms. The features were best seen under the phase-contrast microscope. The cuticle shows very indistinct outlines of elongated cells, often with small round pits that may be the sites of silica granules upon their longitudinal walls. The darker oval bodies $40\mu \times 30\mu$ and apparently with an aperture, are thought to be stomate. They are surrounded by a definite wall, the apertures are all parallel, and all about 20μ long.

The surface features of the leaves and internodes are alike, and correspond with those seen on the cuticle. There are cells with rather indistinct walls, $45\mu \times 60\mu$, and small pits about 10μ in diameter in roughly longitudinal rows. However, stomata were not seen.

Discussion.

It is certain that the stems were not much lignified, the longitudinal ribs being probably cortical fibres and vascular tissue. The difference in form of these ribs upon the internodes and between the nodal furrows has been noted, but an interpretation is not offered.

(a) The Leaf.

The midrib forms a furrow on the upper side of the leaf, and a ridge on the lower, except at the base, where it cannot be seen. I think the leaf was originally strap-shaped over most of its length but round in section near the base. The evidence that the leaf base is rounded comes from a specimen where it is laterally compressed, but appears scarcely narrower than usual. This is supported by the absence of any marked twist in the leaf bases, e.g. in specimen V.31857, for the cellular striæ are parallel to the leaf margins for their whole length. The little trench around the leaf bases is regarded as being due to the collapse of the thick tissues into a mould formed by the lower surface of the organ (Walton 1936), and this surface, exposed in transfer, is seen to be without a trench.

(b) The Leaf-Sheath.

At the most the leaf-sheath could only be 2–3 mm. long, i.e. the distance between the nodal furrows ; however, it is believed that a leaf-sheath is either minute or non-existent. The complex and jagged upper nodal furrow would appear to represent the broken lower end of the internode above. If this is so there is no projecting leaf-sheath, and at best there might be a closely adpressed

one.   The specimens were examined for mud enclosed within the substance of the fossil, but none was discovered ; neither could any sign of an epidermal layer within the carbonaceous matter be seen.   Thus the sheath must either be very closely adpressed indeed, or virtually non-existent, the leaves being joined to the stem where they appear to join.   But there might possibly be an extremely minute collar of tissue, perhaps 0·2 mm. wide, joining the leaves together at their point of departure from the stem.   The preservation does not permit an opinion on this.

The surface of the lower node on specimen V.31860 appears to show broken cells ; this is regarded as being caused by the leaves tearing off from the surface of the node.   This view favours interpreting the ribs between the two nodal furrows as decurrent leaf bases.   No view is put forward concerning the nature of the lower nodal furrow.

Comparisons.

Phyllotheca brookvalensis does not fit comfortably into any existing genus, but is nearest to *Phyllotheca* and *Neocalamites*.   The significant features are contrasted below, and it is considered that it is best regarded as a *Phyllotheca* in which the leaf sheath is reduced to a vestige.

(1) The leaves are certainly in lateral contact at the base, unlike *Neocalamites*, and a minute sheath may be present.

(2) The vascular bundles of the internode are not prominent, and there appears to be one per leaf, as in *Phyllotheca*, but not as in *Neocalamites*.

(3) The nodal region, measured longitudinally, is 2–3 mm. broad and complex, unlike that in *Neocalamites*.

(4) The leaves show no conspicuous transverse striæ, agreeing with *P. australis*, but differing from *Neocalamites*.

The only specimen which I suspect to be identical with *P. brookvalensis* is " *Neocalamites hoerensis* " of Walkom (1915) from Denmark Hill, Ipswich (Queensland), from rocks of upper Triassic age.   Its leaves are fairly similar, and the internodes are fairly short, while the nodes seem to show two transverse lines about 3·0 mm. apart.   It differs only in being slightly larger.

The Ipswich specimen, which appears to be the only one of its kind in the flora, is unlikely to be *N. hoerensis*, for at least in Greenland there are always a large number of leafless pith-casts associated with such leafy shoots of *N. hoerensis* (Professor Harris, personal communication), and no suitable pith-casts have been either figured or described in the material from Ipswich.

Another specimen called *N. hoerensis* from Bellevue near Esk (Walkom 1924) probably of the same age as " *N. hoerensis* " from Ipswich (Jones & de Jersey 1947), seems to differ in several respects from *Phyllotheca brookvalensis*.

Dun (1912) records the genus *Phyllotheca* in list form only from, apparently, the same horizon at Brookvale without giving a specific name.

Species Now Removed from *Phyllotheca*.
Equisetites minuta (Arber) n. comb.
Text-figs. 4, D, E ; 5, C-H.

1886   *Vertebraria novæ-zeylandica* Hector, fig. 30, 4, on p. 65.
1917   *Phyllotheca minuta* Arber, p. 27, pl. 2, figs. 5, 9.
1947   *Phyllotheca minuta* Jones & de Jersey, p. 76.   (Mentioned in a species list.)
      Phyllotheca scolowskii Schmalhausen (1879) is very similar.

Equisetites minuta was first described and figured as a new species by Arber (1917).   It was placed by him in *Phyllotheca* on the characters of the leaf sheath. Certain articulated stems were mentioned, but not definitely ascribed to any

genus or species.   The record by Hector consists of a rather small figure without either description or discussion.

The material for the present description was collected by the British *Discovery* Expedition from Mount Potts and the Clent Hills, New Zealand, the two localities mentioned by Arber.   The material is in the Department of Geology, British Museum.   The plants are preserved in a black shale, and are somewhat graphitized.

Diagnosis.

Leaf sheath 3 mm.–5 mm. long, 10 segments (9–11), separated by narrow commissural grooves about $0·2$ mm. across and $0·2$ mm. deep.   Segments flat or slightly convex at the node, becoming (sometimes) concave away from the node.

Surface covered with cellular striæ, enclosing cells $25\mu \times 40\mu$ elongated longitudinally.   Stomata not seen.   Transverse striæ also present, 100μ long, 5μ wide, about 24μ apart.   Leaf sheath adpressed to stem.

Internode tissue very delicate, commissural furrows continuing on to internode for about 4 mm., not so distinct as on leaf sheath.   Surface between and below furrows smooth.   Cellular and transverse striæ present, as on leaf-sheath.   Internode length unknown, at least 7 mm.

Leaves with entire margins, at least 5 mm. long, pointed, W-shaped in section, side flanges of the " W " pointing up the stem.   Midrib at top of angle between side arms, fine, visible for half length of leaf, and on inside of sheath to position of diaphragm.   Width of leaves at point of attachment, $2·0$ mm. at top of side arms, about $0·2$ mm. less at bottom of side arms.   Leaves spreading at about 90° to stem, surface with cellular striæ as on leaf-sheath, transverse striæ not present.

Diaphragm nearly width of node, preserved in position, of thick rather uniform tissue, showing radiating cells $30\mu \times 25\mu$, concave into next internode below.   Showing (as seen from below) a central raised region (the central boss) clearly divided from the outer rim, half width of diaphragm.   Elongated depressions, rather obscure, about $1·5 \times 0·5$ mm. present, passing from edge of the central boss on to outer rim (probably), twice as many as leaves.

Cuticle not preserved.

Description.

The fossils mostly comprise the nodal region and leaf-sheath, with the free parts of the leaves broken off ; and upon certain of these (see Text-fig. 5, F, G) there are relics of internodal tissue.   There are also one or two very short lengths of internode preserved in position.   The free leaves are preserved in three cases (Text-figs. 4, D, E ; 5, E).

Where the leaf-sheath is preserved vertically to the bedding and viewed from below, it appears cup-like, and has been so described by Arber (1917).   It is suggested that this cup-like appearance is due to compression of the matrix, and therefore of the fossil.   Assuming that lateral distortion of a compression is less important than vertical (Walton 1936), it may be that the original width of the tissues of the node is preserved nearly as in life ; whereas the length of the sheath has been reduced to about one-tenth of its original length.   Thus as viewed from below the sheath appears nearly as broad as high.

There is a small trench around the leaf bases as seen from below, or a ridge as seen from above.   This is discussed below.

In several specimens (Text-figs. 4, E ; 5, E) there is a shelf around the inside of the sheath at a level where a few scraps of carbon (probably from the diaphragm) are preserved on the matrix.   This shelf is regarded as the remains

G

of an abscission of the next internode above. In two specimens this shelf is wider and has the form of a concave furrow. Since these two specimens are practically at right angles to the bedding, the width of this furrow is regarded as giving the width of the internodal tissues in life; i.e. 0·3 mm., or thereabouts. Scars, as for example of vascular tissue, were not seen in this furrow.

When the leaf sheath is preserved intact the nodal diaphragm appears to be the whole width of the node, for no break in the radial rows of cells on the diaphragm can be seen, except for a very narrow one which corresponds in
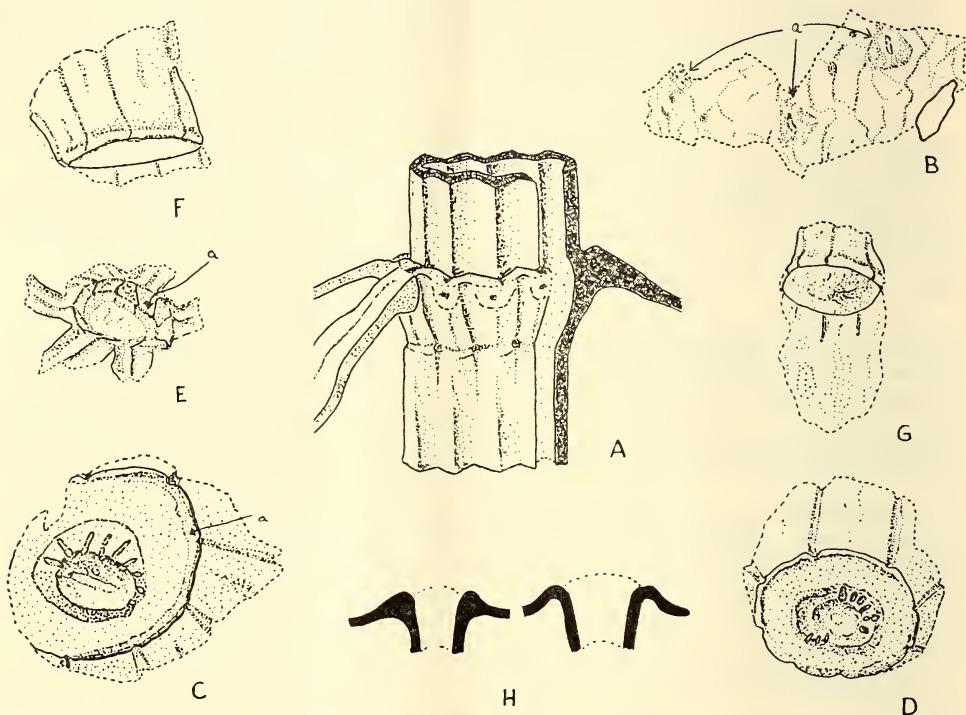
Fig. 5.—A, B, *Phyllotheca brookvalensis*; C–H, *Equisetites minuta*.

A. Reconstruction of the nodal region of *P. brookvalensis*.

B. Portion of epidermis with cell outlines and pits (? stomata), ×100. V.31862c, British Museum.

C, D. Nodal diaphragm, with leaves broken off, to show radiating marks on the central part of the diaphragm, ×2. V.15707 and V.15660, British Museum. (a=furrow believed to represent position (and thickness) of next internode below.)

E. Node and leaves, seen from above, showing inside surface of the stem at a node. (a=shelf, believed to represent point of attachment of next internode above), ×2. V.15660, British Museum.

F, G. Node, nodal diaphragm and portions of internodal tissue. F with polished diaphragm as if slickensided, ×2. V.15660 and V.15661, British Museum.

H. Diagram to show two possible interpretations of the form of the leaf sheath.

position to the shelf on the leaf-sheath. Where the leaf-sheath has been broken so as to expose the stem (Text-fig. 5, F, G) the thickness of the sheath is about 0·1 mm., and the width of the diaphragm about 0·2 mm.

The internodal tissue (except for the short lengths noted above) is only preserved as delicate wisps. As viewed from the inside of the stem, the continuation of the commissural furrows appear as ridges. Between these the

tissue is smooth, or else raised in wrinkles whose form strongly suggests irregular shrinkage in compression and not original features of the plant.

The form of the leaves has been noted in the diagnosis. The vertical height of the side flanges is about $0 \cdot 1$ mm. The end of the leaf was seen plainly in one case only, the side flanges draw together till in section the leaf is almost V-shaped. Since the leaves are only preserved in those specimens where the sheath lies at right angles to the bedding, and there are at 90° to the stem, it is believed that the leaves did normally diverge from the top of the sheath at about 90°.

The diaphragm does not show a wheel-like arrangement with " hub ", " spokes " and " rim " ; though the elongated depressions may be of the same nature as the " spokes " of the diaphragm of *E. lateralis*, for example. The elongated depressions are only distinct in a segment of two diaphragms, but where they are present there are twice as many as there are leaves in the same segment. In this respect they resemble the metaxylem masses at the node of a modern *Equisetum*.

In specimen V.15660 (Text-fig. 5, F) the diaphragm has the surface features obliterated. This is believed to be similar to the polishing of " slickensides ".

Interpretation.

It seems clear that the internode lacked appreciable woody tissue for it is only a very thin layer of carbon without strands of coal. It has been suggested that the tissues of the internode were $0 \cdot 3$ mm. or so thick. The diaphragm, on the other hand, was massive, for it has resisted crushing, and also, since it is not found rotated in the present material, was probably firmly attached at its edges.

The trench, or furrow, around the leaf bases may have two explanations : it is not possible at present to decide between them, see diagrams at Text-fig. 5, H

(1) The leaves did not diverge at once from the top of the sheath, but were thin and not fleshy.
(2) That the upper and lower surfaces of the leaf were not parallel, i.e. the leaf was fleshy, and the coaly material has collapsed into a mould formed by the leaves before compression.

It is not known whether the leaves were photosynthetic or not.

Comparisons.

Equisetites minuta is in many respects intermediate between a modern *Equisetum*, e.g. *E. fluviatile*, and *Phyllotheca*, e.g. *P. australis*. Features of comparison are set out below, and it is concluded that *E. minuta* is probably best placed in *Equisetites* (or *Equisetum*).

(*a*) Points of similarity with *Equisetites* :

(1) Smooth internode, the downward continuations of the commissural furrows dying away on the internode.
(2) Solid nodal diaphragm.
(3) Form of the leaf with side flanges pointing up the stem.

(*b*) Points of similarity with *Phyllotheca* :

(1) Free leaves at least at long as the sheath.
(2) Free leaves spreading out from the stem.

Some alleged nodal diaphragms have been described from *Phyllotheca* (Heer, 1877 ; Schmalhausen, 1879 ; Chapman, 1927) the last record being of rather doubtful value, but it seems clear that they are not of wide occurrence in the genus ; certainly in *P. australis* and *P. indica* there is no sign of one.

Equisetites minuta may be compared with certain fossils of similar dimensions, usually placed in *Equisetites* (or *Equisetum*).

(1) *E. nicoli* Arber (1917), also Edwards (1934). This New Zealand species differs in being somewhat larger, in having twice as many leaves, and in having a diaphragm with " hub " and " spokes " as in *E. lateralis*. It agrees, however, in the spreading leaves which are at least as long as the sheath.

(2) *E. hollowayi* Edwards (1934). This plant also is from New Zealand, but is less similar. Its internode is ribbed and the leaf teeth are 2 mm. long and adpressed. The diaphragm has a wheel-like form but not so obviously as *E. nicoli*.

(3) *E. natgonensis* Oishi (1940) differs in its ribbed internode and adpressed leaves. The diaphragm is not known.

(4) *E. duvallii* Saporta (1873). This species differs in its short, narrow, adpressed leaf teeth, but its diaphragm and internode are similar.

(5) *E. bunburyanus* (see Salfeld, 1909), *E. gracilis* (see Halle, 1908), *E. blandum* (see Raciborski, 1894) and *E. muensteri* (see Harris, 1931), are all usually rather larger than *E. minuta*, and also differ in their relatively short and adpressed leaf teeth.

There are two plants which have been included in *Phyllotheca* which resemble *E. minuta* in size and in their rather short spreading leaves.

(1) *P. sibirica* Heer (1877) differs in its wheel-like diaphragm (just like *E. lateralis*). Its leaves look flatter.

(2) *P. scolowskii* Schmalhausen (1879) is very similar indeed in all respects except, possibly, the diaphragm which seems to show obscure " spokes " and a " rim ".

Discussion.

Phyllotheca is probably not a natural group, though a useful one. The Upper Carboniferous species nearly all appear to resemble *Annularia*, and in one case (*P. robusta* Feistmantel, 1880) *Lobatannularia*, as closely as they do the Type. Most of the post-Triassic species look, at least in figures, as if they might equally well be placed in *Equisetites*.

Phyllotheca australis is a Southern Hemisphere Permian species, often associated with *Glossopteris*. There is in the same region a group of species, namely *P. indica*, *P. muelleriana*, *P. zeilleri*, *P. griesbachi* and *P. leptophylla*, which closely resemble *P. australis* and one another. *P. deliquescens* also comes into this group, though it is found both in the *Glossopteris* region and also in the Siberian Permian (Sahni, 1926 ; Hirmer, 1927), but it may be composite. The similar but poorly known *P. uluguruana* is from the lowermost Trias of South Africa. These species may form a related group ; they have already been compared with *P. australis*, and the affinities of *P. australis* will be considered with relation to them alone. I will term these species the " *australis* group ".

The distinction between *Phyllotheca* and *Equisetites* (*Equisetum*) has never been very clear. For example, the character distinguishing *P. australis* given by Brongniart (1828) was leaves spreading out from the sheath. However, *Equisetum columnare*, which Professor Harris tells me has a typical *Equisetum* cone (to be described) sometimes also has spreading leaves, and other incompletely known species like *E. laterale* and *E. minuta* regularly have. No character seems to hold for all species of *Equisetites* or the " *australis* group ", comparisons rather tend to emphasize the similarity between the two. The following points, therefore, cannot be rigid distinctions. In *P. australis* the leaves are spreading, and at least as long as the sheath ; the leaves are flat (i.e. not M-shaped on the abaxial side) ; and the ribs which continue the midrib on to the stem are prominent, while the commissural furrows on the stem are inconspicuous. In

addition no member of the " *australis* group " has been found with a diaphragm, except one uncertain determination which I have rejected, see above.

Cones have now been found in four species of *Phyllotheca*, *P. australis* Brongniart (herein described), *P. deliquescens* (Goeppert) Schmalhausen (1879), *P. uluguruana* Gothan (1927), and *P. rallii* Zeiller (1899). A further fragmentary cone from America has been described by Arnold (1953) as *P. cf. rallii*. Its age is (probably) early Pennsylvanian, i.e., Middle Upper Carboniferous.

In *P. australis* the cone axis is large and bears alternating distant whorls of bracts and sporangiophores. The bracts are numerous (about 30 in a whorl) and form a sheath round the sporangiophores. The sporangiophores are few (six or seven in a whorl), are twice branched with a stout basal portion. The ultimate branches are thin and the reflexed sporangia are few in number and borne on small delicate heads.

In *P. deliquescens* the axis is smaller, and bears rather distant whorls of bracts which are basally united into a sheath, but whose free teeth are spreading and as long as the sheath. The bracts correspond, I presume, to those of *P. australis*. About midway between each bract whorl there are quite a number of large peltate sporangiophores, each bearing six or more sporangia. The sporangiophores appear to arise separately from the cone axis. The sporangiophores are not obviously whorled, but the cone has usually been interpreted as consisting of occasional whorls of bracts separating several whorls of sporangiophores. There is another interpretation which I would like to bring forward : that there is but one whorl of sporangiophores between each bract whorl and that the sporangiophores are branched, but in the cortex of the stem. On this view the structure of the cone of *P. deliquescens* is essentially the same as that of *P. australis* ; but on the usual view they are so different that a new generic name would be needed for *P. deliquescens*.

P. uluguruana is a small cone (rather badly preserved) but more like *P. deliquescens* than *P. australis*.

P. rallii is fairly like *P. australis* on vegetative characters, but showing little resemblance in its cone. The cone is extremely slender, and was apparently borne on a leafy shoot, with alternating whorls of long bracts and whorls of four or five delicate sporangiophores. The sporangiophores are definitely unbranched and bore four sporangia on a small head. *P. rallii* I believe resembles *Calamostachys* more closely than it does *Phyllotheca australis* (cf. Gothan, 1927), and accordingly I have left *P. rallii* out of account in framing a diagnosis of *Phyllotheca*.

Hitherto the affinities of the Type species, *Phyllotheca australis*, have not much been considered because it is little known, but attention has been concentrated on *P. deliquescens*. Largely on cone characters this species has been considered as intermediate between a Calamite and *Equisetum*, perhaps nearest to *Equisetum*. The bract whorls have been dismissed as " occasional ". The cone of *P. australis* recalls *Calamostachys* in its regular alternation of bracts and sporangiophores. In *Calamostachys* there are twice as many bracts as sporangiophores (occasionally up to three times as many) but in *P. australis* there must be about five times as many. The branching of the sporangiophores is most exceptional in the Equisetales and removes it from close affinity with any other genus. I suggest that *P. deliquescens* is organized on the same lines as *P. australis* but the sporangiophore branching is condensed and the resemblance to *Equisetum* secondary.

Branching of the sporangiophores is normal in the Sphenophyllales and Hyeniales, but *P. australis* shows no other point of approach to either group. I regard *Phyllotheca* (of the " *australis* group ") as an aberrant member of the Equisetales which has retained the early ancestral character of branched sporangiophores.

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ILMENITE FROM BEACH SANDS OF NEW SOUTH WALES.

By C. E. Curnow
and L. G. Parry.*

With two Text-figures.

Communicated by Professor R. S. Nyholm.

Summary.

The grains of the natural mineral ilmenite, as found along the coast of New South Wales, are not uniform in respect of either physical properties or chemical composition.

Part A of this paper deals with some important properties of the grains contained in these impure concentrates from ore-dressing aspects. Herein are discussed qualitatively the magnetic, chemical and crystallographic properties of the grains, the occurrence of chromium and the effects of heating the grains in air. The properties of several grades of concentrate, selected by magnetic means, are also discussed.

In Part B of this paper are discussed some properties of the ilmenite concentrate revealed by an examination using magnetic and X-ray diffraction methods. The oxidation products of the ilmenite are also considered and possible structures are suggested for these products.

I. Introduction.

Along the coast of eastern Australia, heavy beach sands are concentrated by wave action into commercially useful ore deposits. The minerals present are rutile, zircon and ilmenite, together with small quantities of monazite, garnet and cassiterite. The deposits are worked principally for rutile, and zircon and the flow sheet usually shows washing and gravitational concentration, drying, electrostatic separation and magnetic separation.

These minerals have already been studied from various points of view (Whitworth, 1931 (occurrence) ; Poole, 1939 ; Jones, 1946 (general description) ; Stilwell and Baker, 1948 (occurrence of " chromite ")).

Part A of the present investigation concerns the ilmenite component from beaches of New South Wales ; this is a mixed iron-titanium oxide (theoretically $FeO.TiO_2$) but the presence of small quantities of chromium makes it generally unsaleable at present. Two possible avenues of commercial interest are :

(a) The production of an ilmenite concentrate with a chromic oxide content less than 0·1 per cent., which is the limit generally specified for the manufacture of white TiO_2 pigment, and

(b) the production of a concentrate enriched in chromium.

Independent investigations on ilmenite from Queensland, closely related to the present studies, have been carried out jointly by the C.S.I.R.O. and the Mining Department of the University of Melbourne, more or less simultaneously with

* School of Applied Physics, New South Wales University of Technology, Broadway, Sydney.

the work here reported. Their results have been described in their report No. 461, " Separation of Chromite from Ilmenite from North Stradbroke Island, Queensland ".

In Part B the magnetic properties of the natural ilmenite are outlined, together with those of the products resulting from roasting the original concentrate. The constitution of the grains is discussed in conjunction with the known properties of mixed oxides of iron and titanium.

PART A.

II. ILMENITE* AND ASSOCIATED IMPURITIES.

Some minerals found in beach sands are diamagnetic, while others are paramagnetic or ferromagnetic. The diamagnetic grains for most practical purposes are unaffected by magnetic fields ; they experience very small forces in the direction of decreasing field strength. Paramagnetic grains will tend to move in the direction of increasing field strength. In these two cases, the magnetic properties may be summarized conveniently by measuring the magnetic susceptibility, which is small and independent of the strength of the magnetic field. For ferromagnetic or ferrimagnetic grains the forces act in the direction of increasing field strength ; the magnetic susceptibility is larger than for paramagnetic materials, and it is field dependent. A high intensity magnetic separator will remove strongly paramagnetic grains as well as ferromagnetic grains and it was found that the commercial ilmenite concentrate ranges from paramagnetic to weakly ferromagnetic. Pouillard (1950) and Chevallier (1951) find that pure ilmenite is paramagnetic ; the magnetic susceptibility quoted by these authors is comparable with that of some of the grains in the ilmenite concentrate.

In order to simplify the problem of locating the chromium impurity, the ilmenite concentrate was divided into sixteen magnetic fractions on a laboratory separator which lifted the grains vertically. These fractions were labelled A to P inclusive. The fractions A, B and C were rejected since they were highly magnetic, had a high iron content, and X-ray investigations showed the presence of free magnetite as well as ilmenite ; they comprised approximately 2 per cent. by mass of the original concentrate. The fractions O and P were shown to differ markedly from the remaining fractions. O comprised approximately 6 per cent. by mass and is discussed in detail below. P comprised 1 per cent. by mass of the concentrate and was mainly garnet and monazite.

The fractions were studied using magnetic and X-ray diffraction methods. A mineragraphic examination was made and representative samples were assayed. The results of these experiments, shown in Table 1, may be conveniently summarized as follows :

(i) Mineragraphic examination showed that grains in fractions D to N inclusive did not exhibit any regular variation in grain structure or appearance. In general, the grains are anisotropic under normal polarized reflected illumination and each grain extinguishes uniformly, although occasional structures suggesting twinning are apparent.

(ii) Spectroscopic evidence shows traces only of vanadium, silicon, magnesium and aluminium in addition to the important constituents titanium, iron, chromium and manganese. In order to examine the mode of occurrence of manganese and chromium in each of the fractions, sets of appropriate numbers of grains were excited in an arc until there

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* The ilmenite concentrate studied in detail was supplied by National Minerals Pty. Ltd., Newcastle, and the results refer specifically to this product.

was no residue and the spectrographic plate was examined to see if the intensity of the spectral lines was constant, or varied in discrete units. Thus for fraction G, which showed an analysis of $0 \cdot 09$ per cent., Cr_2O_3 (v. Table 1), 250 grains were counted for each spectrum and two exposures showed strong chromium lines which were absent in ten other exposures. Sets of spectra, with appropriate numbers of grains in each excitation, were taken for all the fractions. These experiments revealed that

> (a) in the fractions D to N inclusive of the ilmenite concentrate there are two kinds of grains present, one kind being small in number and rich in chromium, while the other kind is ilmenite containing less than about $0 \cdot 01$ per cent. Cr_2O_3, and
>
> (b) manganese is uniformly distributed throughout the ilmenite grains.

TABLE 1.
Properties of Magnetic Fractions.

Fraction.	Percentage Weight Distribution.	Volume Susceptibility, e.m.u. $\times 10^{-3}$.	Chemical Analysis.				
			Weight per Cent. of Sample.				$\dfrac{Fe^{+++}}{Fe^{++}}$
			TiO_2.	Fe.	Cr_2O_3.	MnO.	
A+B+C							
D	2	$11 \cdot 0$	$46 \cdot 9$	$37 \cdot 0$	$0 \cdot 36$	$2 \cdot 2$	$0 \cdot 64$
E	12	$8 \cdot 7$			$0 \cdot 15$		
F	16	$4 \cdot 3$			$0 \cdot 09$		
G	7	$3 \cdot 8$	$49 \cdot 7$	$36 \cdot 8$	$0 \cdot 09$	$2 \cdot 3$	$0 \cdot 51$
H	13	$2 \cdot 3$			$0 \cdot 097$		
I	10	$1 \cdot 4$			$0 \cdot 093$		
J	4	$1 \cdot 3$			$0 \cdot 11$		
K	5	$0 \cdot 65$	$51 \cdot 8$	$35 \cdot 2$	$0 \cdot 09$	$2 \cdot 6$	$0 \cdot 44$
L	6	$0 \cdot 62$			$0 \cdot 09$		
M	11	$0 \cdot 52$			$0 \cdot 09$		
N	5	$0 \cdot 467$	$50 \cdot 1$	$34 \cdot 3$	$0 \cdot 24$	$1 \cdot 6$	$0 \cdot 39$
O	6	$0 \cdot 32$			$13 \cdot 0$		

> (iii) The magnetic properties given above are obtained by extrapolation to low magnetic field intensities and show the contribution of ferromagnetic effects to the apparent magnetic susceptibility. It is significant that the changes in magnetic susceptibility appear to correlate well with the Fe^{+++}/Fe^{++} ratio.
>
> (iv) The chromium occurs principally in grains of low magnetic susceptibility, approximately 80 per cent. of the chromium occurring in fraction O, while fractions E to M have an average chromic oxide content of $0 \cdot 1$ per cent.
>
> (v) The manganese content is uniformly distributed through the fractions and is approximately 2 per cent., estimated as MnO.

It has been observed (U.S. Bureau of Mines, 1934, R.I. 3223) that some ilmenite ores change their magnetic properties after being heated in air. The chromium-free ilmenite grains from each of the above fractions of ilmenite concentrate were examined at room temperature after heating in air to temperatures between 600 and 800° C. The material exhibits the properties of a

two-phase system, one being more highly magnetic than the original ilmenite and which will be referred to as " magnetic ilmenite " and the other resembling rutile (see Part B). The average magnetic susceptibility of these grains, after being heated, is greater than that of the original ilmenite grains.

Compared with the ilmenite grains, the chromium-rich grains which were obtained from fraction O show little change in magnetic susceptibility when heated to 700° C.

To test the application of a knowledge of these properties to the industrial separation of the ilmenite from the chromium-rich grains, a sample of commercial ilmenite concentrate was separated magnetically into three fractions on a " Rapid Magnetic Separator ". (In addition a small quantity of monazite and garnet passed through the separator.) The properties of these three fractions were as follows :

(1) The highly magnetic fraction, containing magnetite, ilmenite and intermediate minerals, was rejected since it contained an appreciable amount of chromium. This fraction comprised 9 per cent. by mass of the original concentrate.

(2) The " middling " fraction comprised 80 per cent. of the original concentrate and contained $0 \cdot 20$ per cent. Cr_2O_3, 50 per cent. TiO_2 and $2 \cdot 5$ per cent. MnO.

(3) The fraction from the third pole comprised 12 per cent. of the original material and contained 10 per cent. Cr_2O_3.

Further adjustment of the poles should result in a " middling " fraction with chromic oxide content equal to or less than the commercial limit of $0 \cdot 1$ per cent. In order to obtain an ilmenite with lower chromium content, the above " middling " fraction was heated to a temperature between 700 and 750 °C. for 15 minutes and cooled in air. It was then separated magnetically, 84 per cent. being taken as magnetic ilmenite. This magnetic ilmenite comprised more than 65 per cent. of the original ilmenite concentrate and contained $0 \cdot 05$ per cent. chromic oxide. The chromic oxide content might be reduced even further by a magnetic separator with a slow feed or a lower field gradient which would prevent the grains of magnetic ilmenite clinging together, thus mechanically occluding non-magnetic chromium-bearing grains.

The least magnetic fraction was also roasted under the above conditions and cooled. A further magnetic separation removed about 45 per cent. as magnetic ilmenite containing $0 \cdot 2$ per cent. Cr_2O_3, leaving a residue containing 18 per cent. Cr_2O_3.

PART B.—ILMENITE AND THE OXIDATION PRODUCTS.

III. ILMENITE FRACTIONS.

Chemical assays, X-ray powder photographs and mineragraphic examination indicate that fractions D to N inclusive are very closely related materials. X-ray diffraction powder photographs, taken with an $11 \cdot 46$ cm. Debye Scherrer camera, do not give any significant variations in interplanar spacings between the different fractions and the patterns may be indexed in accordance with the work of Posnjak and Barth (1934). In these determinations the accuracy of the interplanar spacings is indicated by the following d values :

$$2 \cdot 720 \pm 0 \cdot 005 \text{ Å.}$$
$$1 \cdot 497 \pm 0 \cdot 001 \text{ Å.}$$

The variations in magnetic properties are closely correlated with the Fe^{+++}/Fe^{++} ratio (v. Table 1), but the values of susceptibility quoted include a

maximum contribution by the ferro-magnetic components of the crystal. The susceptibility measurements were obtained using the Gouy relative method with
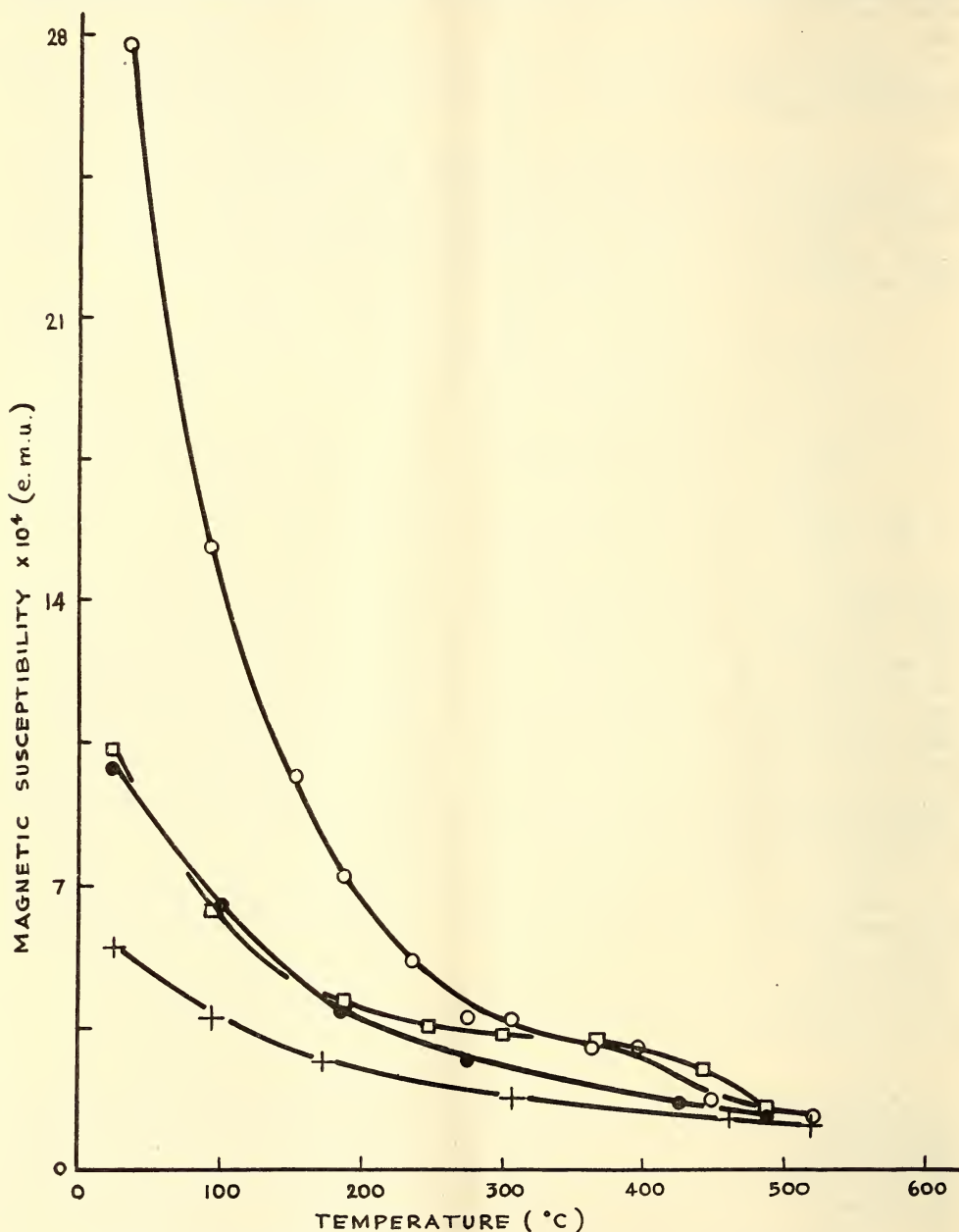
Fig. 1.—Comparative Curves of Magnetic Susceptibility v. Temperature.
Fraction G –O–   Fraction N–+–   Fraction K –●–   Mixture (N+10% magnetic ilmenite+1% magnetite) –□–.

$FeSO_4(NH_4)_2SO_46H_2O$ as the standard. In order to determine the cause of the ferro-magnetism a set of curves (Fig. 1) was obtained in a Sucksmith type ring balance showing the variation of volume susceptibility with temperature.

All fractions give curves with steep gradients and show a diminution of magnetic susceptibility at $200 \pm 50°$ C. This is not consistent with the presence of minute inclusions of free magnetite or γ ferric oxide unless these materials have markedly different Curie temperatures due to solid solution effects (Michel *et al.*, 1951).

IV. The First Oxidation Product.

An investigation was made of the effects of controlled roasting of ilmenite in air. The magnetic properties of natural ilmenite grains are unaffected by being heated in air to temperatures up to approximately 400° C. (The initial drying prior to the electrostatic and magnetic separations of the beach sands has negligible effect on the properties of the ilmenite mineral.) When heated to temperatures in excess of 600° C. rapid oxidation results and a relatively stable end product is obtained, which on cooling shows much higher magnetic susceptibility than any of the natural fractions. The rapidity of this oxidation depends on the temperature and the ilmenite fraction which was used. This final product has been referred to as " magnetic ilmenite ".

The magnetic properties of this material were studied at room temperature by using it as a core of one of a pair of previously matched inductance coils connected in series opposition. The coil system was placed in the gap of an electromagnet. The out of balance e.m.f. due to changes of magnetization of the core caused a deflection of a ballistic galvanometer which was related to the change in intensity of the magnetization of the specimen. The demagnetization field within the grain is uncertain, but an average magnetization loop was measured and the coercive force was estimated to be 200 oersted, which is greater than the coercive force of 50 oersted for fraction G. The initial magnetic susceptibility was found to be $1 \cdot 5 \times 10^{-2}$ e.m.u., without correcting for the packing of the grains.

The temperature variation of the volume susceptibility of " magnetic ilmenite " was studied under vacuum in a Sucksmith type ring balance and the resultant variation is shown in Fig. 2, the Curie point being $120 \pm 30°$ C.

Chemical analysis shows that FeO comprises up to 20 per cent. by mass of the " magnetic ilmenite " and that the ratio of Fe^{+++} to Fe^{++} reaches a value of approximately $1 \cdot 3$.

The X-ray powder photograph of " magnetic ilmenite " shows two superimposed patterns. One of these agrees closely with the interplanar spacings of rutile as given in the A.S.T.M. crystallographic card index (1945). The second pattern cannot be distinguished from the patterns of the original ilmenite fractions as regards interplanar spacings and visual estimates of line intensities. Using the Geiger counter X-ray spectrometer, further investigations were made of the rutile line (Bragg angle $15 \cdot 9°$) and the ilmenite line ($18 \cdot 9°$ Bragg angle). These lines were compared in samples of " magnetic ilmenite " and mixtures of known amounts of rutile and ilmenite. The result was that the amount of rutile in the oxidation product was 10 ± 1 per cent.

These results suggest that when an ilmenite fraction is heated to a temperature about 700° C. there is a decrease in the Fe^{++} content to a limiting value when the ratio Fe^{+++}/Fe^{++} is approximately $1 \cdot 3$ and that by the time this ratio has been reached some rutile has separated as a second phase.

Results on synthetic materials quoted by Pouillard (1950) give the limit of solid solution of Fe_2O_3 in ilmenite to be reached when Fe^{+++}/Fe^{++} is equal to 1. The discrepancy between the ratio Fe^{+++}/Fe^{++} for " magnetic ilmenite " and this synthetic limiting solid solution may be partly due to interference by manganese in the lattice structure. It seems probable then that the magnetic ilmenite is a

multiphase system, the principal components being rutile and a product with
the general formula

$$(Fe^{+++}{}_{2y}Fe^{++}{}_{1-y}Ti^{++++}{}_{1-y})O_3$$
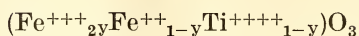
where y is approximately one-third. This product may represent the end point
of a series of compounds which includes the original fractions of the ilmenite.
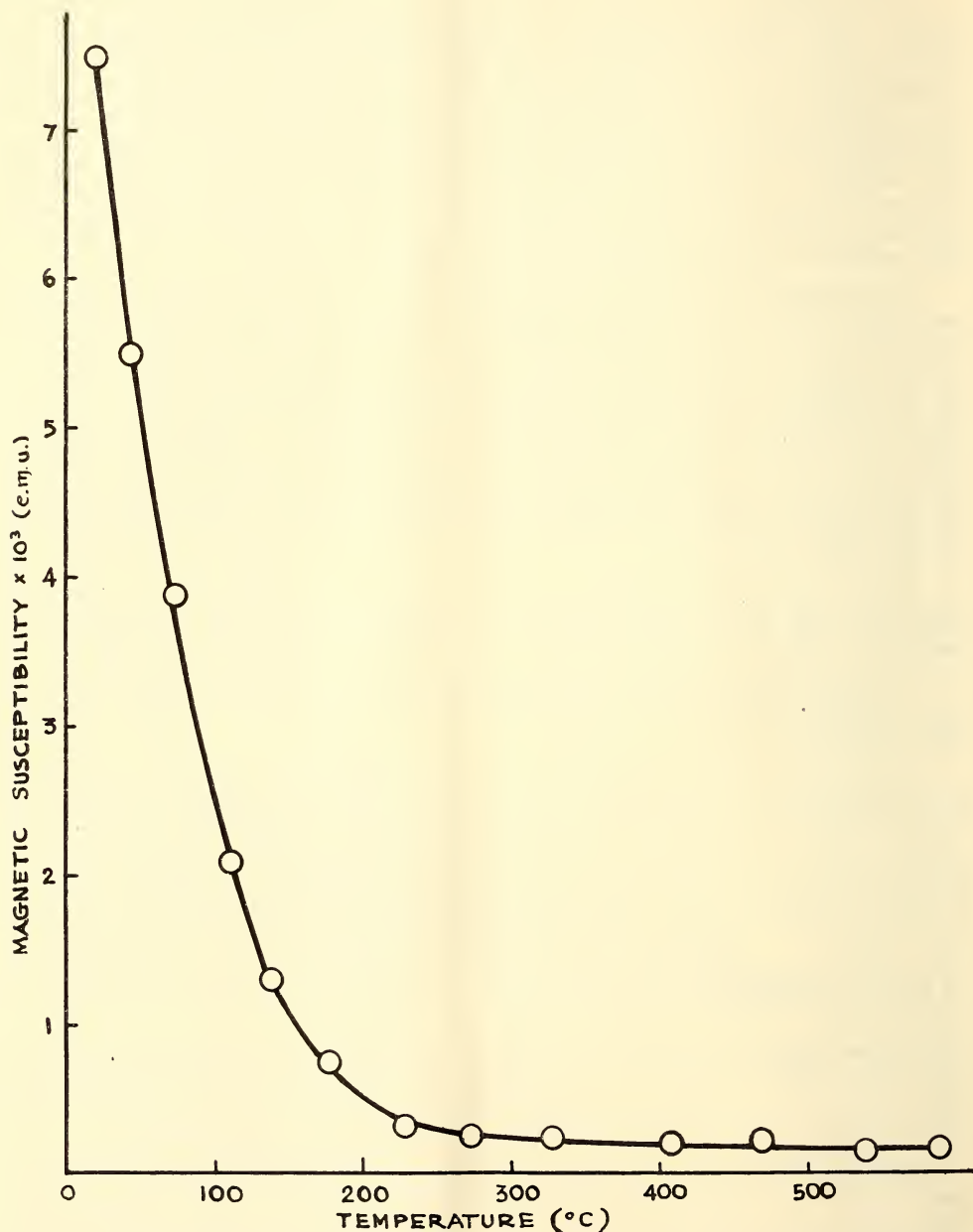
Fig. 2.—Temperature dependence of magnetic susceptibility for " magnetic ilmenite ".
(Applied magnetic field approximately 1250 œrsteds).

V. Second Oxidation Product.

When any of the original ilmenite fractions or " magnetic ilmenite " is heated in air to a temperature in excess of 850° C., the oxidation is rapidly completed with the formation of a material, referred to below as " iron titanite ", which on cooling has a magnetic susceptibility of $(3 \cdot 26 \pm 0 \cdot 08) \times 10^{-4}$ e.m.u., which is equal to that of fraction O.   The temperature variation of susceptibility does not follow the Curie-Weiss Law.

The density of this material is $4 \cdot 27$ g. cm.$^{-3}$ and its streak is brown. Chemical analysis shows considerable oxidation of the iron leaving a very low FeO content which probably tends to zero after prolonged roasting.

TABLE 2.
X-Ray Data for Iron Titanate (Angstrom Units).

Complete Pattern d Value (Relative Intensity).		Rutile Pattern d Value (Relative Intensity).		Residual Pattern d Value (Uncorrected).	Tetragonal Indices (hkl).
4·73	3			4·73	(100)
3·425	8			3·425	(110)
3·192	3	3·24	8		
2·722	10			2·722	(102)
2·49	1	2·49	7		
2·427	2			2·427	(200)
2·370	2			2·370	(112)
2·197	2	2·19	4		
2·170	2			2·170	(210)
1·957	7			1·957	(202)
		1·877	4		
1·851	7			1·851	(113)
1·734	4			1·734	(220)
1·673	4	1·69	10		
1·652	4			1·652	(004) (221)
1·626	4			1·626	(203) (300)
1·534	10			1·534	(310)
1·495	<1	1·495	2		
1·490	<1			1·490	(311) (114)
1·415	6			1·415	(312)
1·374	1			1·374	(204)
1·353	5	1·353	8	1·353	(223)
1·309	<1	1·309	2		
1·215	1			1·215	(411)
		1·141	4		
1·093	2	1·095	5	1·093	(332)
1·080	4	1·077	5	1·080	(420)
1·036	3	1·041	5	1·036	(413)
1·027	3	1·031	6	1·027	(422)
		1·022	5		
1·011	2			1·011	(333)
1·000	4			1·000	(206) (315)
0·954	3			0·954	(510)
0·925	8			0·925	(432) (502)

The X-ray powder photograph shows a different pattern from those obtained previously ; it may be resolved into a rutile pattern, similar to that obtained in " mágnetic ilmenite " together with a set of other lines which is shown in Table 2, column 3.   This residual pattern has been indexed on a tetragonal chart and the Miller indices are shown in Table 2, column 4.   The lattice parameters are $a = 4 \cdot 86$ Å., $c = 6 \cdot 63$ Å., $c/a = 1 \cdot 36$.

The A.S.T.M. crystallographic index (1953) gives the d values and relative intensities for ferric titanite, $Fe_2O_3.TiO_2$. The powder pattern closely resembles that of the above final oxidation product.

Pouillard (1950) has synthesized iron (ferric) titanite for which he quotes the structure as being tetragonal with lattice parameters a = 9·30 Å., c = 9·50 Å., c/a = 1·02. The chemical formula is $Fe_4(TiO_4)_3$.

Since tetragonal structures are not common in the iron-titanium oxide series, and since the final oxidation product has all the iron in the trivalent state, it is suggested that it is a form of iron titanate, probably very similar in structure to that represented by the formula $Fe_2O_3.TiO_2$ above.

VI. ACKNOWLEDGEMENT.

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THE OCCURRENCE AND GENESIS OF PYRRHOTITE AND CHALCOPYRITE IN SEDIMENTS NEAR ROCKLEY, NEW SOUTH WALES.

By R. L. Stanton.

Abstract

Significant quantities of sulphide have been found in carbon-bearing tuffaceous shales of the Rockley district, N.S.W. The sulphide is principally pyrrhotite, but minor associated chalcopyrite is also present. It is concluded that the pyrrhotite results from the metamorphism of FeS_2 originally deposited by bacterial action during sedimentation. The copper of the chalcopyrite has probably been derived, during sedimentation, from decaying marine organisms, such as molluscs and, during diagenesis and later metamorphism, from the volcanic fragments in the shales.

Introduction.

In another paper[*] it has been noted that abundant sulphide occurs in certain dark shaly sediments near the village of Rockley, in central western N.S.W. The purpose of the present paper is to describe in some detail the mode of occurrence of this sulphide, and to discuss its genesis.

I. Description of the Occurrence.

Although several minor occurrences of sulphide-bearing sediments are known in the area, the principal one, and that on which the present note is based, outcrops in Campbell's River, at the foot of Mt. Lawson—about six miles due south of Rockley. Owing to the presence of alluvium, and to discontinuity of outcrop, the exact extent of the sulphide-bearing formation cannot be stated, but it is certainly some hundreds of feet thick and of the order of three to four miles in strike length.

The sediments containing the sulphide are the uppermost members of the Triangle Creek Group, and immediately underlie the andesitic tuffs of the Rockley Volcanics. Their bedding, which is very well preserved, dips fairly consistently at about 60° to the east, and it is clear that the structure here is a small, tight anticline, as described in the other paper. The rocks are dark and fine-grained, and although bedding is clear on weathered surfaces and in thin sections, it would not be distinct in the fresh hand-specimen were it not for the presence in it of the abundant sulphide. Development of the latter varies among the fine bedding lamellæ, and as a result delineates many of these rather beautifully. Most of the enclosing shales show good conchoidal fracture, and the intersection of such fractures by sulphide-rich beds produces a striking series of curved lines on the fresh surface.

As seen under the microscope, the shales are clearly highly tuffaceous. The general silicate assemblage is quartz-chlorite-biotite-tremolite, and with

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[*] In preparation.

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this are abundant carbon and the sulphide. Quartz is the most abundant silica compound, constituting rather more than 30% of the rock and occurring as small interlocking grains ; the larger of these are up to 0·1 mm. across, and average size is approximately 0·04 mm. diameter. Chlorite is very pale green and is developed interstitially to the quartz. Some of it has been converted, during regional metamorphism, to biotite, which occurs as rather indefinite, pale brown, slightly pleochroic clots up to about 0·1 mm. across. The most striking member of the silicate assemblage is the tremolitic amphibole, which in the form of laths and needles up to 0·5 mm. long. This amphibole, which is presumably of volcanic origin, is a feature of all thin sections examined, and usually is almost as abundant as the quartz.

In the thin sections it is the carbon that delineates the bedding. It occurs as minute wisps and flakes almost throughout the rocks, but its variation in abundance from one bedding lamella to another shows these up very sharply. The width of the latter varies from a fraction of a millimetre up to about 3·0 cm.

As the sulphide particles are opaque, only their shape and size, and their relationships with the other minerals can be observed in thin sections. For the most part, they are much larger than the associated silicate particles. Some are more or less equidimensional, but most are in the form of elongated spindle-shaped bodies up to 0·4 cm. in length. Many of these closely parallel the bedding. Under high magnifications the sulphide shows very irregular boundaries and includes abundant silicate. In the opinion of the writer there is no tangible evidence of replacement of the silicates by the sulphide and it seems most likely that both groups—in their present form at least—developed more or less simultaneously. A rather obvious feature of the sulphide occurrence is its preference for the rather coarser, carbon-poor bands of the enclosing shale. As it seems to occur only in carbon-bearing rocks, it might have been expected that, within these, the sulphide would have shown some preference for the carbon-rich bands but the opposite seems to be the case.

Examination of polished sections in reflected light shows quite clearly that the bulk of the sulphide is pyrrhotite. It is of characteristic pinkish cream colour, and shows faint pleochroism from a pale to a rather brownish pink. Anisotropism is strong, with yellow, green and blue-grey interference colours. Much of it is in the form of individual crystals, or twinned crystals. In some cases, an individual pyrrhotite body is in the form of an aggregate of grains, though this is apparent only under crossed nicols.

About 15% of the pyrrhotite particles contain flecks of chalcopyrite and in isolated cases this has been found forming almost a half of an individual spindle. The small chalcopyrite particles always occur as a part of a given pyrrhotite body—it has not been found as discrete grains, or as grains merely in contact with the latter. The appearance of the polished sections suggests that the chalcopyrite and pyrrhotite have either formed together with the development of composite particles, or that chalcopyrite has replaced the pyrrhotite.

No pyrite or other sulphides have been found.

II. GENESIS OF THE SULPHIDES

(a) *Pyrrhotite.* There can be little doubt that the pyrrhotite has developed in the shales as the result of one or other of two processes.

  (i) Hydrothermal activity, with resultant metasomatic replacement of the shale by pyrrhotite.

  (ii) reduction of marine sulphates, with the deposition of iron sulphide as a syngenetic feature, and later conversion of FeS_2 to pyrrhotite, presumably during metamorphism.
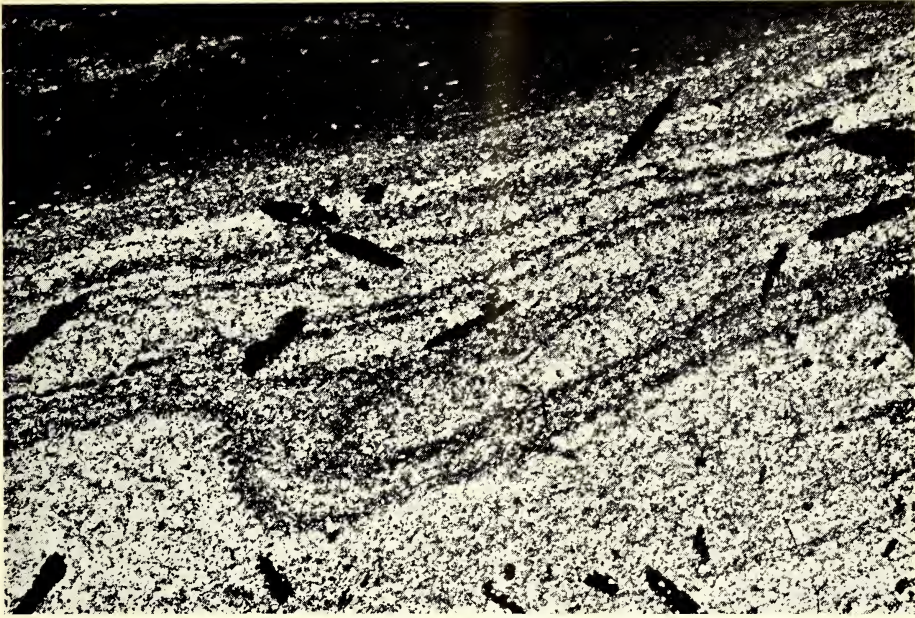
Fig. 1.—Spindle-shaped grains of pyrrhotite within carbonaceous shale. The band showing in the upper part of the photograph is almost pure carbon. Spindles show irregular boundaries and much included material. Ordinary light, ×8.

Fig. 2.—Polished section of the carbonaceous shale viewed in reflected light, showing portion of a pyrrhotite spindle. The irregularity of the boundaries and the abundance of included material are obvious features. Ordinary light, ×95.

The present writer considers the first of these to be unlikely, though it is recognized that it cannot be entirely dismissed. A point against it is the fact that the nearest intrusive rock (and that is only a sill) is about eight miles from the deposit, and the nearest post-folding intrusive more than nine miles distant. Neither of these intrusions has produced mineralization near its boundaries. Further, the lack of any features suggesting replacement of silicate by sulphide, at least in its present form, supports the case against a hydrothermal origin.

It is considered most likely that the deposit formed as a result of the second process, or one at least very similar to this.
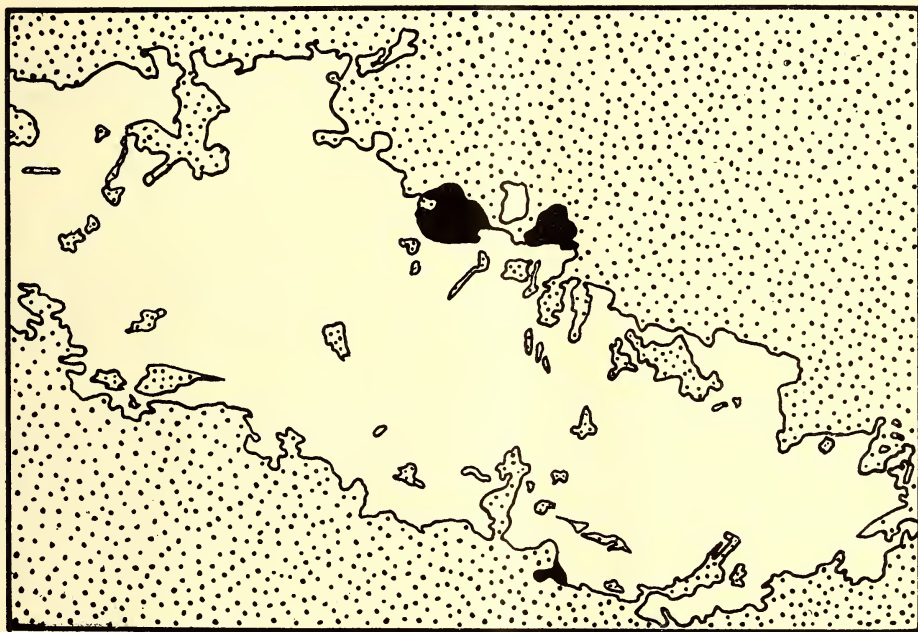
Text-fig. 1.—Tracing from Plate II in which, owing to the similarity in reflectivity of pyrrhotite and chalcopyrite, these two minerals cannot be distinguished from each other. Pyrrhotite (unshaded) is shown included in carbonaceous shale (stippled) and carrying small marginal bodies of chalcopyrite (black).

Comparatively little seems to be known of the mechanism of syngenetic deposition of iron sulphide in marine muds, but it has been suggested that combination of iron compounds with bacterial H_2S or sulphur first produces hydrotroilite ($FeS_x.nH_2O$ or $FeS.nH_2O$). This is converted, by addition of sulphur, to " melnikovite " (shown by X-ray work of Niggli to be finely divided pyrite) and finally to pyrite or marcasite depending on the pH of the environment.

The H_2S and sulphur required for the formation of the troilite and pyrite are normally produced by the activities of sulphate-reducing bacteria. The group of organisms involved are capable of reducing sulphates and other oxygen-rich compounds—such as the thiosulphates—to H_2S, and are strictly anaerobic, their principal development being at depths exceeding 10 to 20 cm. below the mud-water interphase (Zo Bell, 1947) in a normal marine environment. Further, they are heterotrophic, and obtain their energy from decaying carbonaceous matter. As sea-water offers an almost unlimited supply of sulphate for these organisms, it is on the distribution of carbonaceous matter that their occurrence

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depends ; hence, in turn, the formation and distribution of troilite in the marine muds depends on the distribution of decaying organic material. This correlation between the organic carbon content of black muds and their ferrous sulphide has, in fact, been shown by Galliher (1933) in some modern marine sediments.

Baas Becking (personal communication) has concluded that the conversion of marine hydroxides to the sulphides is probably on the following pattern :

    (i) Assuming the formation of H_2S by bacterial sulphate reduction, this encounters, in solid phase, ferrous and/or ferric hydroxides

$$H_2S + Fe(OH)_2 \rightarrow FeS + 2H_2O$$
$$3H_2S + 2Fe(OH)_3 \rightarrow 2FeS + S + 3H_2O.$$
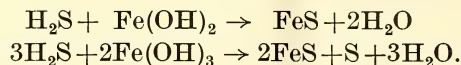
Thus the primary product of the interactions of H_2S and the hydroxides is triolite, and both FeS and sulphur are present at the mud-water interphase.

    (ii) FeS_2 is then formed by

$$FeS + S \rightarrow FeS_2$$
$$2FeS + 2H_2S + O_2 \rightarrow 2FeS_2 + 2H_2O.$$
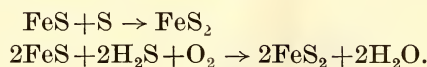
This may then develop as pyrite or marcasite according to the prevailing pH. Recently Edwards and Baker (1951) have shown that marcasite forms at pH values below $6 \cdot 5$, pyrite at values above this. As the pH of sea-water varies above about $6 \cdot 8$, conversion of troilite to pyrite should always occur in a marine environment.

It is thought that the iron sulphide in the black shales of the Mt. Lawson area deposited as a result of processes essentially similar to those outlined. The energy source for the bacteria was presumably cellulose from decaying benthonic flora. Whether the bottom waters were stagnant or not is of course unknown ; as anaerobic conditions prevail at only a few centimetres below the mud-water interphase even in shallow, well-aerated waters, this seems of no consequence. As suggested by the recent marine biological studies, initial deposition would have been as troilite, which then combined with sulphur or H_2S to form stable pyrite. Once in this form, the iron and sulphur were removed from the sulphur cycle, and the sulphide accumulated as minute particles disseminated throughout the sediment.

Just why the sulphide should now appear to have developed preferentially in the rather coarser, carbon-poor, beds is not at all clear. It is possible, though there is no experimental evidence to support such a suggestion, that this distribution is a compaction and metamorphic effect. During diagenesis and later folding, the sulphide may have suffered a general migration to the more open material, depositing as aggregates there, rather than in the tighter, fine shale, bands.

That the pyrrhotite itself has developed during regional metamorphism seems very likely. Although it has been suggested (Blanchard, 1938 ; Garretty, 1943) that pyrrhotite may form at low temperatures, the experimental work of Allen, Crenshaw and Johnson (1912) has shown that, at atmospheric pressure, the dissociation

$$FeS_2 \leftrightarrows FeS(S_x) + (1-x)S$$
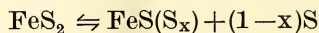
takes place at 575° C. At the pressures prevailing during folding and regional metamorphism, its temperature of formation is probably in the vicinity of 600° C. This strongly suggests that pyrrhotite is indeed a high temperature mineral. It therefore seems certain that the pyrrhotite itself was not formed until some considerable time after deposition of the sediments, and it is most

probable that it developed, during folding, as a product of the regional meta-morphism of the syngenetic pyrite.

(b) *Chalcopyrite.* If one excludes the possibility of a hydrothermal origin for the chalcopyrite, there are two possible sources of the required copper :

(i) *Marine.* It is well known that traces of copper occur both in sea-water and in the tissues of marine organisms. Such copper, in encountering free sulphur and/or H_2S, would have been precipitated as the sulphide in precisely the same way as the iron.

(ii) *Volcanic.* Work on modern volcanoes (e.g. the classical works on the Mediterranean volcanoes and that of Allen, Zies and Fenner on the fumeroles of the Valley of Ten Thousand Smokes) has shown that significant quantities of copper and other heavy metals are given off during eruptions. The analytical work of Sandell and Goldich (1943) has shown that the older lavas contain appreciable copper and other metals, and qualitative spectrographic work carried out by the present writer on the Palæozoic volcanic rocks of the Mt. Lawson area indicates considerable quantities of copper in these too. It has already been pointed out that the sulphide-bearing shales contain a large volcanic fraction, and it is considered that this may have supplied at least some of the copper of the chalcopyrite.

It seems very possible that either one, or both, of these factors have contributed.

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DISTRIBUTION OF LOWER CRETACEOUS FORAMINIFERA IN BORES IN THE GREAT ARTESIAN BASIN, NORTHERN NEW SOUTH WALES.

By IRENE CRESPIN.*

(Communicated by IDA A. BROWNE.)

ABSTRACT.

Forty-nine bores have been examined for the Water Conservation and Irrigation Commission. One hundred and two genera and species of foraminifera have been recognized, the assemblage being dominated by arenaceous forms. Three characteristic zones have been determined which should be useful in further work in the area.

INTRODUCTION.

Early in 1940, the Commonwealth Geological Adviser, Dr. W. G. Woolnough, suggested to the Water Conservation and Irrigation Commission of New South Wales that a micropalæontological examination of samples from bores being drilled in the Great Artesian Basin in northern New South Wales might assist in elucidating geological and stratigraphical problems in that area. This request was readily agreed to and the first consignment of samples was received for micro-examination by the writer in June, 1940, the samples coming from No. 1 Bore, Kiga, near Moree. No microfossils were found in this bore, but an interesting assemblage of foraminifera of Lower Cretaceous age was found in subsequent bores. Little was known of the foraminifera in deposits of Lower Cretaceous age in Australia, and after examining the foraminifera from several bores around Bourke the writer published a paper in this Journal in 1944 in which some new and known species were described and figured. Since 1940 samples from forty-nine bores have been submitted for micropalæontological examination from an area extending from Tibooburra in the north-west of the State to Mungindi in the north-east (see Locality Map). As a result of the examination of these bores, a characteristic assemblage of foraminifera, including many new species, has been discovered. New forms and known species were described recently (Crespin, 1953). As a result of the study of these forms the distribution of the foraminifera in the area can be outlined and characteristic zones in the bores defined. Unfortunately the excellent set of assemblage slides of foraminifera made during the examination of the majority of bores was destroyed by fire in 1953, but the species described in the above paper are preserved in the Commonwealth Palæontological Collection at Canberra.

HISTORICAL NOTES.

Lower Cretaceous foraminifera were first recognized in Australia by Charles Moore, who, in 1870, discovered them in the deposits at Wollumbilla, 24 miles east of Roma, Queensland. Howchin, in 1884 and 1895, identified and described foraminifera from the Lower Cretaceous rocks of the Great Artesian Basin of

BORE LOCALITIES
NORTHERN NEW SOUTH WALES
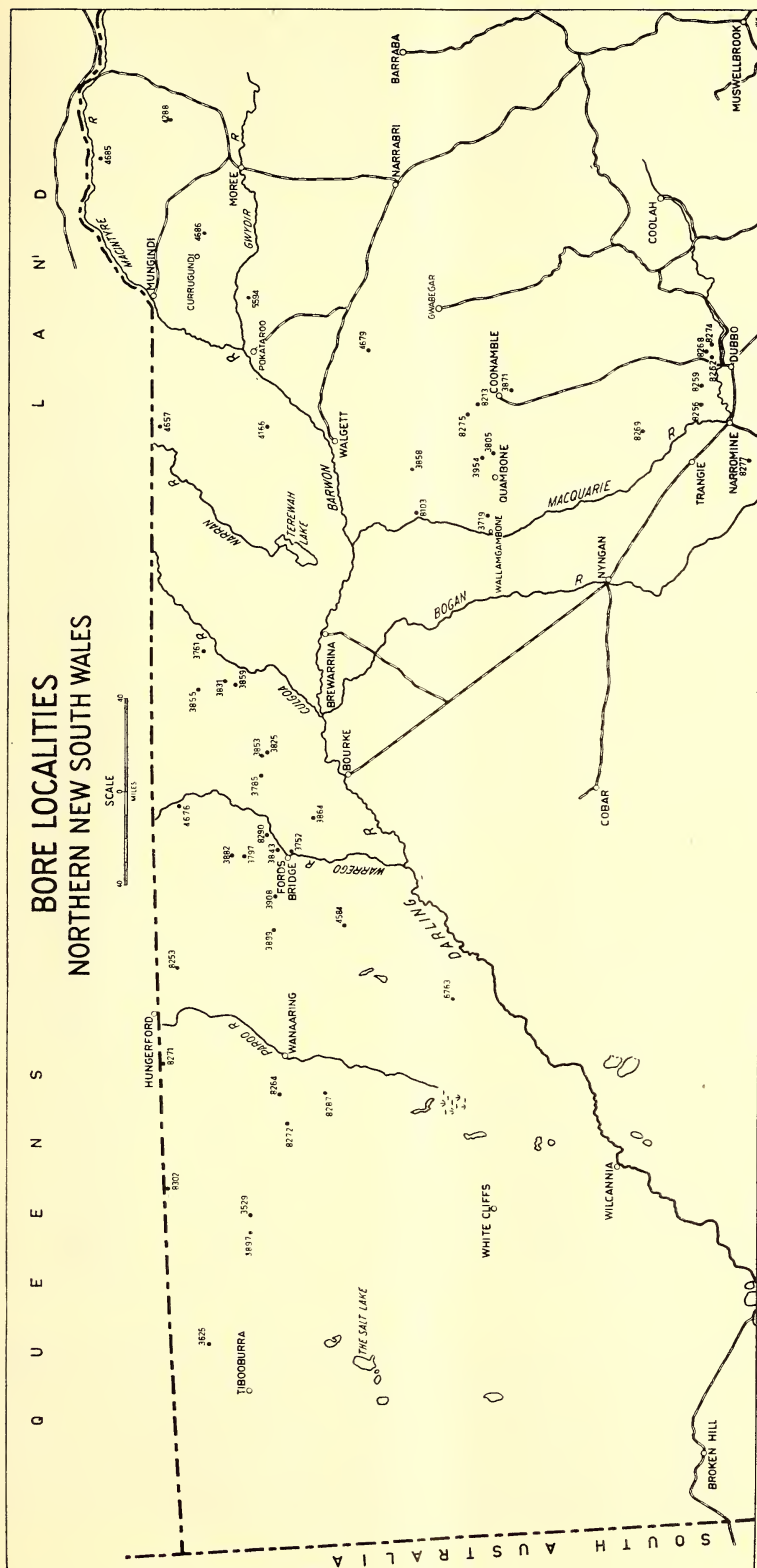
northern South Australia. Crespin (1944 and 1953) described several new species from outcrops and bores in the Great Artesian Basin of Queensland, northern New South Wales and South Australia. In 1945 she listed foraminifera from deposits in the Great Artesian Basin in an unpublished departmental report. Kenny (1934) discussed the resources of subsurface waters of north-western New South Wales and Rade (1954) dealt especially with the bores in

TABLE 1.

Bores in Northern New South Wales Examined for Microfossils.

Bore Number.	Locality.	Number of Samples.	Limiting Depths of Samples Examined. (Feet.)	Limiting Depths of Samples Containing Microfossils.
3625	Mt. Wood Station, Tibooburra ..	3	2078–2088	N.F.
3897	C. M. and W. E. Taylor, Eurella Downs, White Cliffs (1)	6	1125–1450	1200
3529	W. Gilby, Wonga, White Cliffs (2)	5	1450–1845	1450–1600
8302	J. J. Doohan, Yarralee, Wanaaring (3)	19	100–1150	450–1000
8272	Department of Agriculture, Wanaaring (4) ..	15	280–1000	350–1000
8264	E. W. Robinson, Womparley, Bourke (5)	22	50–1105	1000–1050
8287	E. J. Riches, Myrnong, Bourke (6)	13	50– 650	200– 650
6763	D. L. J. Murray, Goolgumble, Bourke (7)	19	25– 375	77– 360
8271	K. F. Robinson, Talyeale, Hungerford (8) ..	27	100–1400	200–1000
8253	R. J. Dunk, Warroo, Bourke (9)..	22	50–1000	250– 800
3899	A. V. Jackson, Wampra, Bourke (10)	12	3– 774	170– 688
3908	J. P. O'Shannessy, Cooncoobie, Bourke (11) ..	20	2–1185	502– 840
4584	Berriwinnia Pastoral Company, Toorale, Bourke (12)..	11	22– 681	121– 395
3882	J. Hatch, Ellaville, Bourke (13)	10	3– 534	365– 414
3797	A. Holmes, near Ellavale, Bourke (14)	16	50– 750	280– 750
3752	G. M. Taylor, Ford's Bridge (15)	16	25–1067	275– 425 (No samples between 425′ and 1067′)
3843	A. Holmes, Kerribee, Bourke (16)	24	100–1536	100–1300
8290	J. T. O'Connor, Shannon, Bourke (17)	12	41–1135	250–1000
3864	P. J. McGirr, Lauradale, Bourke (18)	30	50–1619	350–1000
4676	P. Mallon, Avoca, Bourke (19)	14	817–1000	817–1288
3785	W. R. Johnston, Calooma, Bourke (20)	82	11–1553	325– 575
3825	E. W. Langbein, Bullaroon, Bourke (21)	31	50–1700	250–1000 (No samples between 250′ and 950′)
3853	,, ,, (22)	10	28– 386	100– 386
3855	W. L. Fennell, Bourke (23)	12	7– 427	158– 376
3859	,, ,, (24)	28	1– 977	498– 977
3831	,, ,, (25)	30	6–1118	237– 963
3761	C. C. Horden, Caringle, Brewarrina	6	1564–1850	N.F.
3719	J. W. Fisher & Son, Wallangambone	20	1564–2015	N.F.
8103	J. H. Fisher, Lochinvar, Carinda (26)	15	3– 802	254– 802
3858	I. A. F. Dent, Wangrawally, Walgett (27) ..	34	25–1568	300–563
8277	E. Jones, Willoughby, Narromine	7	25– 175	N.F.
3954	Mrs. D. McLeish, Thurn, Coonamble	62	0–2130	N.F.
3805	Mrs. E. F. Bennett, Muttama, Quambone ..	59	17–1984	N.F.
4657	No. 1 Yerranbah, Moree	30	274–3303	N.F.
4166	No. 1 Dungelar, Moree	31	25–3781	N.F.
8269	Estate F. E. Body, Bundemar, Trangie ..	25	25– 475	N.F.
8213	T. N. Tym, Trenton, Coonamble	4	1630–1796	N.F.
8275	C. L. Sanderson, Woolinga, Coonamble	3	515– 630	N.F.
3871	Scottish Australian Co., Warrana, Coonamble ..	19	864–1842	N.F.
8256	M. E. Howe, Retreat, Dubbo	11	25– 275	N.F.
8259	L. Fitzell, Marathon, Dubbo	4	25– 100	N.F.
8262	A. J. Burns, Montrose, Dubbo	6	25– 150	N.F.
8268	E. A. Hennessy, Fair Oakes, Dubbo	14	25– 350	N.F.
8274	R. W. Collett, Iona, Dubbo	7	25– 200	N.F.
4679	Woorana Pastoral Co., Walgett	41	2–2168	N.F.
5594	Neargo No. 2, Moree	81	50–3132	355–1450
4686	Curragundi Bore, Mungindi (29)	60	50–3523	650–1150
4685	Boronga No. 2, Mungindi (30)	138	25–4570	725–2054
4288	Kiga No. 1, Moree	26	3232–4197	N.F.

the Moree district in a paper in which he quoted an unpublished departmental report by the writer on Boronga No. 2 Bore. The list of foraminifera given in this paper by Rade was prepared in 1942, when little work had been done on the Lower Cretaceous foraminifera in Australia. Consequently many of the determinations given there have been revised. The writer has prepared many unpublished departmental reports on the bores in northern New South Wales on behalf of the Water Conservation and Irrigation Commission since 1940.

SOURCE OF THE MATERIAL EXAMINED.

More than 1,100 samples have been examined for microfaunas from the 49 bores listed in Table I, and these cover more than 45,000 feet of drilling. Most of the bores penetrated the main aquifer which occurs in sands at the base of the Cretaceous. Of these 49 bores, samples from 30 contained foraminifera and some radiolaria and ostracoda ; it is noticeable that all of the bores containing microfossils are located in the vicinity of the northern boundary of the State. Samples from bores drilled in the Coonamble, Dubbo, Narromine and Trangie areas, that is in the south-east margin of the Great Artesian Basin, did not contain foraminifera.

For the most part samples were taken at intervals of fifty feet, but in some bores there were large gaps between the depths at which they were collected. In other bores, especially the deeper ones, samples were not taken until considerable depth was reached and consequently the foraminiferal beds were missed or only the basal portion of them was collected. A continuous sequence of samples at 50 feet intervals from which useful zonal information could be derived was available in the following bores :

Bore No. 8253—R. J. Dunk, Warroo, Bourke, from 50 feet down to 1,000 feet.

Bore No. 8264—E. W. Robinson ,Womparley, Bourke, from 50 feet down to 1,105 feet.

Bore No. 8271—K. F. Robinson, Talyealye, Hungerford, from 100 feet down to 1,400 feet.

Bore No. 8287—E. J. Riches, Myrnong, Bourke, from 40 to 650 feet.

Bore No. 8302—J. J. Doohan, Yarralee, Bourke, from 100 feet down to 1,150 feet.

The foraminifera were found in carbonaceous siltstone and carbonaceous sandstone. Glauconite was often common in the basal part of the section, in the beds immediately overlying the friable sandstone containing the main aquifer.

A list of bores examined, together with the limiting depths of samples submitted and the limiting depths between which foraminifera have been recognized, is given in Table I. The bores are listed in an approximate west to east geographical direction across the northern part of the State. Table II shows the distribution of foraminifera in certain bores which have been numbered from 1 to 30 in Table I.

NOTES ON THE FORAMINIFERAL ASSEMBLAGE.

One hundred and two genera and species of foraminifera have been found in the bore samples (Table 2). The general assemblage of species is similar to that found in bores and outcrops throughout the Great Artesian Basin. It is dominated by arenaceous forms, the tests of which are commonly crushed or deflated and usually brownish in colour. These modes of preservation are characteristic of Lower Cretaceous foraminifera in many parts of the world. However, calcareous tests are fairly numerous in some samples and are usually well preserved. The typical arenaceous genera are *Haplophragmoides*, *Ammobaculites*, *Spiroplectammina* and *Trochammina*. The family Lagenidæ is predominant amongst the calcareous forms and in some bores Rotalidæ are present. The commonest genera of the family Lagenidæ are *Robulus*, *Lenticulina*, *Marginulina* and *Marginulinopsis*. The Rotalidæ is represented by *Anomalina* and *Valvulineria*. A few tests of *Globigerina* are occasionally present.

From information derived from bores in which sampling has been at regular intervals, as in the five bores listed earlier, namely Nos. 8253, 8264, 8271, 8287

TABLE 2.

Distribution of Lower Cretaceous Foraminifera in Bores in Northern New South Wales.
The bore numbers correspond to those shown in Table 1.

Foraminifera.	Bores.																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Hyperammina sp.	—	×	—	—	×	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	×	×	×
Ammobaculites australe (Howchin)	—	×	—	—	×	×	×	×	—	×	—	×	—	—	×	×	—	—	—	×	—	—	—	×	—	×	—	—	×	×
Ammobaculites fisheri Crespin	—	—	—	—	×	—	—	—	×																					
Ammobaculites irregulariformis Bartenstein and Brand	—	—	—	—	×																									
Ammobaculites sp.	—	—	—	—	×	—	×	×	—	—	×	—	×	×	×	—	—	—	—	—	—	—	—	—	—	×	—	×		
Ammobaculites minimum Crespin	—	—	—	—	×	×	—	—	—	—	—	—	—	—	—	—	—	—	×											
cf. *Ammobaculites variabilis* Tappan	—	—	—	—	—	—	—	×																						
Ammobaculoides pitmani Crespin	—	—	—	—	×																									
Ammobaculoides romœnsis Crespin	—	—	—	—	×	×	—	×	×	—	—	—	—	—	×	—	—	—	—	—	—	—	—	×	—	—	—	—	×	
Ammodiscus cretaceus (Reuss)	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×							
Ammodiscus cf. *gaultinus* Berthelin	—	—	×	—																										
Ammodiscus sp.	—	—	—	—	—	×	—																				×	—	×	
Reophax cf. *deckeri* Tappan	—	—	—	—	—	×	—	×																						
Reophax cf. *incompta* Loeblich and Tappan	—	—	—	—	×																									
Reophax sp.	—	—	—	—	—	—	—	—	—	—	—	—	×	×																
Lituola camerata Lozo	—	—	—	—	×																									
Lituola cf. *subgoodlandensis* Vanderpool	—	—	—	—	×																									
Pelosina sp.	—	—	—	—	×																									
Pelosina lagenoides Crespin	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×														
Ammomarginulina cf. *cragini* Loeblich and Tappan	—	—	—	—	×																									
Gaudryinella cf. *irregularis* Tappan	—	—	—	—	×																									
Gaudryinella sp.	—	—	—	—	×	—	—	—	—	—	—	—	—	×			×													
Glomospira sp.	—	×	—	—	×	—	—	—	×	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	×
Bigenerina loeblichi Crespin	—	—	—	—	×	—	—	×																						
Bigenerina sp.	—	—	—	—	×	—	—	—	—	—	×																			
Textularia annacoorœnsis Crespin	—	—	—	—	×	—	—	×																						
Textularia sp.	—	×	—	—	—	—	—	—	—	×	×	×	—	—	—	—	—	—	—	×										
Neobulimina minima Tappan	—	—	×	—	×																									
Verneuilina howchini Crespin	⌐	—	×																											
Verneuilina tricarinata d'Orb	—	—	—	—	—	—	—	—	—	—	—	×																		
Verneuilina polystropha (Reuss)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×														
Verneuilinoides schizea (Cushman and Alexander)	—	×	—	×	×	—	×	×	—	—	—	—	×	×																
Spiroplectammina coonanaensis Crespin	—	—	—	×																										
Spiroplectammina cushmani Crespin	—	×	—	—	×	—	×	×	—	×	—	—	×	—	×	×	—	—	—	—	—	—	—	×	—	×	×	×		
Spiroplectammina edgelli Crespin	—	—	—	—	×	—	×	—	×	—	—	—	—	—	—	—	×													
Spiroplectammina sp.	—	—	—	—	—	—	—	—	—	×	×	—	×	×	—	×														
Siphotextularia washitensis Tappan	—	—	—	×	—	—	—	—	—	×																				
Siphotextularia sp.	—	—	—	—	—	—	×	×																						
Haplophragmoides chapmani Crespin	—	×	×	—	×	—	×	×	×	×	—	—	—	×	—	×	×	—	—	×	×	—	×	—	×	×	×	×		
Haplophragmoides concavus Chapman	—	—	—	×	×																									
Haplophragmoides dickinsoni Crespin	—	—	—	×	—	×	—	—	—	×																				
Haplophragmoides cf. *globosa* Lozo	—	—	—	—	—	×																								
Haplophragmoides neocomianus Chapman	—	—	—	×																										
Haplophragmoides sp. nov.	—	—	—	×																										
Haplophragmoides sp.	—	—	×	—	—	×	—	—	—	×	×	—	—	×	—	×	—	—	×	—	×	—	—	×						×
Crithionina sp.	—	—	×	—	×																									
Trochammina depressa Lozo	—	—	—	×																										
Trochammina lattai Loeblich and Tappan	—	×	—	×																										
Trochammina minuta Crespin	—	×	—	×	—	—	×	—	—	—	—	—	—	—	—	×														

TABLE 2.—*Continued.*

Distribution of Lower Cretaceous Foraminifera in Bores in Northern New South Wales.—Continued.

Foraminifera.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Trochammina raggatti Crespin	—	—	—	—	×	—	—	×	×	×	—	—	—	—	—	×	—	×	×	×	—	—	×	—	—	—	—	—	×	×
Trochammina sp.	×	×	—	—	—	×	—	—	—	—	×	—	×	—	—	—	—	—	—	—	—	—	×	×	×	—	—	—	×	×
Quinqueloculina aff. *nana* Loeblich and Tappan	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lagena apiculata (Reuss)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—
Lagena globosa (Mont.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×
Lagena lœvis (Mont.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	×	—	—	—	—	—	—
Enantiodentalina cf. *communis* (d'Orb.)	—	—	—	—	×	×	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Enantiodentalina cf. *debilis* (Berthelin)	×	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lenticulina australiensis Crespin	—	—	—	—	×	—	—	×	×	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—
Lenticulina grata (Reuss)	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lenticulina cf. *gibba* (d'Orb.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—
Lenticulina cf. *sulcifera* (Reuss)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lenticulina cf. *tripleura* (Reuss)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lenticulina tripleura (Reuss)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lenticulina sp.	—	—	—	—	—	×	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	×	×
Astacolus cf. *bronni* (Roemer)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Robulus gaultinus (Reuss)	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Robulus gunderbookaensis Crespin	—	—	×	—	×	×	—	×	×	×	×	—	—	×	×	—	—	×	×	×	—	—	—	×	×	—	—	—	×	—
Robulus warregoensis Crespin	×	—	×	—	×	×	—	×	×	×	×	—	×	×	×	×	—	×	×	×	—	—	—	×	—	×	—	×	×	×
Saracenaria cf. *acutiauricularis* (F. and M.)	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Saracenaria cf. *cypha* Loeblich and Tappan	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Saracenaria cf. *triangularis* (d'Orb.)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Saracenaria sp.	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pseudoglandulina sp. nov.	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pseudoglandulina regularis Crespin	—	—	—	—	×	—	—	—	×	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	×	—
Pseudoglandulina scotti Tappan	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Globulina exserta (Berthelin)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Globulina lacrima Reuss	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—
Globulina cf. *lacrima* Reuss	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	×	—	—	×	—	—	—	—	—	—	—	—	—	—
Globulina minuta (Roemer)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pyrulina fusiformis (Roemer)	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	×	×	×	×	×	×	×	×	×	×	—	×	—	—	—
Pyrulina cf. *gutta* (d'Orb.)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Marginulina bullata Reuss	—	×	—	—	—	—	—	—	—	—	×	—	×	—	×	—	×	—	—	×	—	—	—	×	—	—	—	—	—	×
Marginulina cf. *comma* (Roemer)	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Marginulina aff. *tenuissima* (Reuss)	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Marginulina marreensis Crespin	—	—	×	—	×	×	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Marginulinopsis australe Crespin	—	—	—	—	×	×	—	×	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—
Marginulinopsis parkeri (Reuss)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Marginulinopsis subcretaceus (Crespin)	—	—	×	—	—	×	—	—	—	—	—	—	—	—	—	×	×	—	—	—	—	—	—	—	×	—	×	—	—	—
Vaginulina cf. *complanata* (Reuss) var. *perstita* Tappan	—	—	×	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Vaginulinopsis sp. nov.	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Globigerina planispira Tappan	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Globigerina sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—
Patellina jonesi Howchin cf. *Patellina jonesi* Howchin	—	×	—	—	×	—	—	—	×	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—
Anomalina mawsoni Crespin	—	×	×	—	×	—	×	—	—	—	—	—	—	—	×	—	×	×	—	×	—	—	—	×	—	×	—	×	×	×
Anomalina plummerœ Tappan	—	—	×	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Epistomina australiensis Crespin	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—
Epistomina cf. *caracola* (Roemer)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Eponides sp.	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—
Valvulineria infracretacea Crespin	×	×	—	—	×	×	—	×	×	—	—	—	—	—	—	—	×	×	×	×	—	—	×	×	—	×	×	×	×	×
Gyroidina depressa (Alth.)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	×	—	—	—	—	—	—	—	—	—	—	—	—
Gyroidina cf. *globosa* (Hagenow)	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	×	—	—	—	—

and 8302, it has been possible to determine three characteristic zones which may prove useful in future work in the area :

    (1) A topmost zone in which arenaceous species only have been recognized. No form is predominant enough to be of zonal value.

    (2) A middle zone or zone of *Valvulineria infracretacea*. This species is often associated with *Anomalina mawsoni*. Other calcareous species belonging to the Lagenidæ may be present together with a few arenaceous species.

    (3) A basal zone or zone of *Haplophragmoides chapmani*. *Spiroplectammina cushmani* and *Trochammina raggatti* are also prominent but the two calcareous species *V. infracretacea* and *A. mawsoni* are absent. Calcareous genera such as *Robulus, Lenticulina* and *Marginulina* are usually present.

The striking feature of the Lower Cretaceous assemblage which is dominated by arenaceous foraminifera, is the ability of these forms to live under varied and unfavourable conditions. In the Great Artesian Basin they occur not only in carbonaceous siltstones but also in the sandstone. This fact is also noted by Loeblich and Tappan (1950) in their work on the Kiowa Shale in Kansas, where the assemblage is also dominated by arenaceous foraminifera. The calcareous forms are usually represented by few tests. It seems definite that certain species of arenaceous foraminifera can be used for age determination, whilst others range stratigraphically upwards. This is well illustrated in Western Australia, where the species *Ammobaculites fisheri* Crespin described from the Lower Cretaceous of the Great Artesian Basin ranges up into basal Upper Cretaceous (Cenomanian). Species like *Haplophragmoides chapmani, Spiroplectammina cushmani* and *Trochammina raggatti* as far as is known are restricted to the Lower Cretaceous.

The foraminiferal assemblage suggests that the Lower Cretaceous deposits of the Great Artesian Basin were laid down in a near shore, shallow brackish water environment (Loeblich and Tappan, 1950 ; Bolin, 1954).

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PART II

JOURNAL AND PROCEEDINGS

OF THE

ROYAL SOCIETY

OF NEW SOUTH WALES

FOR

1955

(INCORPORATED 1881)

PART II (pp. 85-130)

OF

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EDITED BY

F. N. HANLON, B.Sc., Dip.Ed.

Honorary Editorial Secretary

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THE AUTHORS OF PAPERS ARE ALONE RESPONSIBLE FOR THE
STATEMENTS MADE AND THE OPINIONS EXPRESSED THEREIN

MINOR PLANETS OBSERVED AT SYDNEY OBSERVATORY DURING 1954.

By W. H. ROBERTSON.

The following observations of minor planets were made photographically at Sydney Observatory with the 13″ standard astrograph and the 8″ Yale camera. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0′·5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were recorded on a chronograph with a tapping key.

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial coordinates was used. Proper motions, when they were available, were applied to bring the star positions to the epoch of the plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time except in cases 168, 175, 192, 200, 224, 227, 228, 230, where each result is from only one image, due to a defect in the other exposure or a failure in timing it. No correction has been applied for aberration, light time or parallax, but in Table I are given the factors which give the parallax corrections when divided by the distance. The serial numbers follow on from those of a previous paper (Robertson, 1954). The observers named in Table II are W. H. Robertson (R), K. P. Sims (S), and H. W. Wood (W). I wish to thank Mr. Sims for some assistance with the computations.

TABLE I.

	1954 U.T.		Planet	R.A. (1950·0)	Dec. (1950·0)	Parallax Factors.
				h m s	° ′ ″	s ″
104	Aug.	12·66903	31 Euphrosyne	22 10 22·98	—48 35 38·4	+0·25 +1·9
105	Sep.	16·52206	31 Euphrosyne	21 34 47·77	—47 54 26·3	+0·13 +2·1
106	Mar.	23·64986	63 Ausonia	13 42 22·83	—17 24 44·4	0·00 —2·5
107	Mar.	31·63879	63 Ausonia	13 36 04·48	—17 23 11·9	+0·05 —2·5
108	Mar.	18·67040	69 Hesperia	13 44 29·45	— 8 13 11·9	+0·02 —3·8
109	Apr.	22·59762	69 Hesperia	13 20 46·81	— 4 11 37·5	+0·14 —4·3
110	Apr.	22·63050	70 Panopaea	14 45 37·33	—12 34 55·7	+0·06 —3·1
111	May	18·53979	70 Panopaea	14 19 00·17	—12 48 44·9	+0·06 —3·1
112	June	18·47739	73 Klytia	15 39 48·96	—22 46 32·6	—0·05 —1·7
113	June	16·67043	82 Alkmene	19 30 08·57	—25 47 14·0	+0·04 —1·4
114	Aug.	9·49466	82 Alkmene	18 45 14·14	—26 54 08·5	+0·05 —1·1
115	Mar.	4·54668	85 Io	10 06 19·72	— 1 49 15·0	—0·02 —4·6
116	May	4·55908	96 Aegle	13 40 27·32	—36 25 43·3	+0·10 +0·4
117	May	18·50552	96 Aegle	13 29 55·45	—35 06 41·7	+0·07 +0·2

I

<div align="center">TABLE I.—Continued.</div>

	1954 U.T.		Planet	R.A. (1950·0)	Dec. (1950·0)	Parallax Factors.
				h m s	° ′ ″	s ″
118	May	20·63684	136 Austria	16 56 51·12	— 7 28 52·4	+0·03 —3·9
119	June	16·54832	136 Austria	16 32 02·29	— 5 30 12·1	+0·04 —4·2
120	Mar.	23·62904	141 Lumen	12 42 13·66	—19 31 35·0	+0·04 —2·2
121	Apr.	22·50526	141 Lumen	12 16 24·58	—17 30 26·8	—0·01 —2·4
122	Sep.	27·61362	154 Bertha	0 48 43·22	—12 02 58·3	+0·05 —3·3
123	Oct.	21·51284	154 Bertha	0 28 45·56	—12 07 07·6	—0·02 —3·2
124	Mar.	4·57390	156 Xanthippe	10 33 09·25	— 8 51 31·4	+0·01 —3·7
125	Mar.	18·64208	192 Nausikaa	13 27 27·73	—15 00 59·5	—0·03 —2·8
126	Apr.	29·49612	192 Nausikaa	12 49 24·78	—12 23 32·0	—0·05 —3·2
127	May	18·68086	213 Lilaea	17 45 40·00	—15 08 30·6	+0·05 —2·8
128	June	15·57694	213 Lilaea	17 24 26·78	—15 33 53·4	+0·01 —2·7
129	Mar.	4·60743	242 Kriemhild	11 23 48·56	— 8 03 53·3	+0·01 —3·8
130	Mar.	23·55550	242 Kriemhild	11 10 15·98	— 5 19 43·4	+0·03 —4·2
131	May	4·62274	249 Ilse	15 23 50·46	—34 47 30·1	+0·04 +0·2
132	June	10·46304	249 Ilse	14 45 18·99	—31 18 34·4	—0·06 —0·4
133	Apr.	1·66918	283 Emma	14 23 51·54	—25 47 03·5	+0·05 —1·2
134	May	6·52804	283 Emma	13 56 53·73	—24 04 44·3	—0·04 —1·5
135	Mar.	3·68424	284 Amalia	12 43 42·45	—15 31 43·9	+0·07 —2·8
136	Mar.	31·57595	284 Amalia	12 21 40·48	—12 58 44·5	+0·01 —3·1
137	July	1·66601	285 Regina	20 39 13·14	—27 14 59·9	0·00 —1·0
138	Aug.	17·50950	285 Regina	19 54 21·72	—23 17 45·2	+0·01 —1·6
139	Aug.	17·56140	303 Josephina	21 01 04·44	—22 07 07·6	+0·04 —1·8
140	Aug.	31·49898	303 Josephina	20 50 50·53	—22 15 27·2	—0·03 —1·7
141	Mar.	25·57808	324 Bamberga	11 44 38·20	— 7 26 57·9	+0·05 —3·9
142	Apr.	12·49732	324 Bamberga	11 30 49·51	— 6 13 06·4	+0·05 —4·1
143	Aug.	17·64207	363 Padua	23 02 41·38	—16 35 27·3	+0·02 —2·6
144	Sep.	22·51771	363 Padua	22 34 06·93	—19 02 41·8	0·00 —2·2
145	Sep.	2·69458	369 Aeria	23 49 11·27	—23 22 26·9	+0·25 —1·9
146	Sep.	23·57630	369 Aeria	23 32 04·35	—25 32 02·6	+0·07 —1·3
147	Sep.	23·61904	381 Myrrha	0 45 12·76	—12 00 38·8	+0·04 —3·3
148	Sep.	27·61362	381 Myrrha	0 42 26·96	—12 25 55·3	+0·06 —3·2
149	Oct.	20·53414	381 Myrrha	0 26 59·20	—14 06 15·8	+0·05 —3·0
150	June	16·63327	389 Industria	18 54 45·87	—24 26 29·5	0·00 —1·4
151	July	23·48772	389 Industria	18 19 59·65	—22 59 51·4	—0·07 —1·7
152	Mar.	25·60972	399 Persephone	12 30 50·85	—11 43 28·9	+0·05 —3·3
153	Apr.	12·55370	399 Persephone	12 14 54·46	—11 16 41·3	+0·06 —3·4
154	Oct.	20·64572	412 Elisabetha	2 57 52·98	— 3 33 08·0	+0·06 —4·4
155	Oct.	21·62476	412 Elisabetha	2 57 07·06	— 3 37 11·4	+0·01 —4·4
156	Nov.	30·49632	412 Elisabetha	2 24 40·85	— 4 07 18·7	+0·02 —4·3
157	May	20·57261	419 Aurelia	15 37 11·93	—18 16 30·0	+0·01 —2·3
158	June	10·51606	419 Aurelia	15 22 31·41	—16 21 09·3	+0·04 —2·6
159	May	20·60335	432 Pythia	16 22 33·79	—10 38 44·2	0·00 —3·4
160	June	15·50565	432 Pythia	15 56 28·95	—13 19 30·6	—0·02 —3·1
161	Apr.	29·62558	447 Valentine	15 27 53·39	—15 58 35·6	+0·01 —2·7
162	June	10·49468	447 Valentine	14 55 58·79	—14 49 00·8	+0·03 —2·9
163	Oct.	20·64572	491 Carina	2 58 19·87	— 2 22 14·1	+0·06 —4·6
164	Oct.	21·62476	491 Carina	2 57 43·91	— 2 31 08·4	+0·01 —4·5
165	June	10·69134	503 Evelyn	19 16 40·54	—25 48 46·6	+0·09 —1·3
166	June	23·63946	503 Evelyn	19 06 22·21	—26 25 40·7	+0·07 —1·1
167	Mar.	4·64564	507 Laodica	12 15 52·14	—14 45 58·6	+0·01 —2·8
168	Apr.	1·54164	507 Laodica	11 55 24·64	—13 17 26·4	—0·03 —3·1
169	May	6·63512	508 Princetonia	15 49 50·67	—23 58 40·8	+0·06 —1·5
170	June	23·48285	508 Princetonia	15 11 52·33	—24 23 31·3	+0·08 —1·5
171	May	18·64217	511 Davida	17 25 21·48	—11 19 37·3	—0·03 —3·4
172	June	24·56072	511 Davida	16 57 46·38	—12 03 12·5	+0·09 —3·3
173	June	28·52900	538 Friederike	17 43 35·97	—15 39 18·0	—0·07 —2·6
174	July	6·54955	538 Friederike	17 37 25·72	—15 50 29·7	+0·08 —2·7
175	Sep.	16·62287	546 Herodias	23 47 55·62	—13 59 04·8	+0·12 —3·0
176	Oct.	5·54018	546 Herodias	23 29 24·52	—14 09 51·2	+0·06 —3·0
177	June	16·63327	554 Peraga	18 57 16·22	—24 21 23·1	—0·01 —1·4
178	July	27·48064	554 Peraga	18 16 31·41	—24 14 00·2	—0·05 —1·5
179	Mar.	8·53586	584 Semiramis	10 27 36·35	— 5 41 05·1	—0·06 —4·1

TABLE I.—*Continued.*

	1954 U.T.		Planet	R.A. (1950·0)			Dec. (1950·0)			Parallax Factors.	
				h	m	s	°	′	″	s	″
180	Sep.	27·65378	598 Octavia	2	02	38·83	—10	57	54·3	+0·02	—3·4
181	Oct.	21·58928	598 Octavia	1	44	40·93	—12	10	39·6	+0·06	—3·2
182	Sep.	16·56921	604 Tekmessa	23	04	21·05	— 9	09	39·3	+0·04	—3·7
183	Apr.	29·57798	656 Beagle	14	27	23·87	—14	07	41·3	—0·01	—2·9
184	Mar.	11·59824	702 Alauda	11	42	09·50	—28	14	35·8	0·00	—0·8
185	Mar.	25·54903	702 Alauda	11	30	19·11	—27	44	40·6	—0·01	—0·9
186	Mar.	15·58350	773 Irmintraud	11	30	34·70	—12	32	07·3	+0·01	—3·2
187	Mar.	31·53639	773 Irmintraud	11	15	51·64	—11	58	44·0	+0·03	—3·3
188	Mar.	3·64901	779 Nina	11	55	13·68	—21	15	50·9	+0·06	—1·9
189	Mar.	23·58666	779 Nina	11	37	41·86	—20	23	27·3	+0·08	—2·0
190	Oct.	6·62902	814 Tauris	2	07	27·36	—25	40	29·7	0·00	—1·2
191	Nov.	10·48250	814 Tauris	1	38	00·28	—23	24	06·0	—0·10	—1·6
192	May	5·65420	897 Lysistrata	16	15	04·58	—29	50	01·0	+0·06	—0·6
193	June	18·47739	897 Lysistrata	15	37	57·38	—22	59	16·1	—0·05	—1·6
194	Mar.	25·64402	932 Hooveria	13	23	16·94	— 8	53	17·6	+0·04	—3·7
195	Apr.	28·51873	932 Hooveria	12	50	34·31	— 7	26	43·6	+0·01	—3·9
196	June	15·66348	953 Painleva	19	03	14·67	—35	36	15·6	+0·08	+0·3
197	June	30·61736	953 Painleva	18	49	54·99	—36	51	22·0	+0·10	+0·4
198	June	29·64450	954 Li	19	44	19·33	—19	45	44·6	+0·04	—2·1
199	Aug.	9·53115	954 Li	19	14	13·72	—21	05	02·1	+0·10	—2·0
200	Apr.	1·62695	955 Alstede	14	02	25·88	—23	29	16·3	—0·04	—1·6
201	Apr.	28·55441	955 Alstede	13	34	27·97	—24	47	22·7	+0·03	—1·4
202	Apr.	29·66383	984 Gretia	16	21	03·59	—34	14	12·5	+0·02	+0·1
203	June	10·57846	984 Gretia	15	42	25·04	—32	36	18·0	+0·22	—0·5
204	Sep.	16·56921	1018 Arnolda	23	00	05·06	— 9	53	25·4	+0·05	—3·5
205	Oct.	5·48948	1018 Arnolda	22	47	13·09	— 8	43	34·1	—0·01	—3·7
206	Apr.	29·57798	1027 Aesculapia	14	30	33·10	—15	10	36·5	—0·01	—2·8
207	Aug.	19·67306	1046 Edwin	23	47	37·50	— 6	57	04·2	+0·03	—4·0
208	Sep.	27·56022	1046 Edwin	23	17	40·21	— 8	41	11·8	+0·08	—3·7
209	Mar.	15·61836	1068 Nofretete	12	20	14·41	— 8	40	32·5	+0·01	—3·7
210	Apr.	13·53156	1068 Nofretete	11	57	05·28	— 6	53	22·5	+0·04	—4·0
211	July	1·53562	1086 Nata	17	39	09·05	—31	45	09·9	—0·02	—0·3
212	July	20·51261	1086 Nata	17	26	02·66	—30	46	27·2	+0·12	—0·5
213	Sep.	2·62864	1115 Sabauda	23	32	27·80	—26	21	30·3	+0·05	—1·1
214	Sep.	22·57222	1115 Sabauda	23	16	41·64	—27	36	18·2	+0·08	—1·0
215	June	29·59196	1126 Otero	18	42	45·41	—33	53	23·1	+0·01	0·0
216	May	5·60613	1135 Colchis	15	34	24·30	—25	39	12·1	—0·01	—1·2
217	May	31·55664	1135 Colchis	15	09	50·75	—24	29	22·8	+0·12	—1·5
218	June	28·57478	1154 Astronomia	18	11	03·74	—24	32	02·1	+0·01	—1·4
219	July	5·54022	1154 Astronomia	18	05	33·46	—24	40	43·1	—0·03	—1·4
220	Apr.	1·59270	1254 Erfordia	12	49	12·83	—16	38	08·8	+0·01	—2·6
221	Apr.	22·54406	1254 Erfordia	12	33	53·90	—14	55	19·5	+0·08	—2·8
222	Apr.	29·57798	1358 Gaika	14	28	12·99	—15	51	44·2	—0·01	—2·7
223	May	31·55664	1415 Malautra	15	12	48·45	—24	48	28·0	+0·11	—1·4
224	Aug.	9·62654	1551 1938 DC₁	21	39	03·57	—17	52	54·7	+0·08	—2·4
225	Sep.	1·52948	1551 1938 DC₁	21	19	15·35	—19	59	41·5	+0·02	—2·1
226	Oct.	5·59581	1569 Evita	0	52	17·92	—14	55	16·2	+0·06	—2·8
227	Aug.	9·62654	1928 RT	21	41	21·72	—17	07	15·0	+0·08	—2·5
228	Aug.	19·60353	1928 RT	21	31	27·12	—17	40	41·2	+0·11	—2·5
229	Aug.	26·53079	1928 RT	21	24	42·45	—17	58	57·1	—0·04	—2·4
230	Aug.	31·53829	1928 RT	21	20	18·12	—18	08	10·5	+0·04	—2·4

TABLE II.

	Comparison Stars.		Dependences.			
104	Cape Ft. 19802, 19817, 19831		0·30797	0·27073	0·42130	W
105	Cape Ft. 19552, 19577, 19589		0·30053	0·36895	0·33052	S
106	Yale *12* I 5169, 5175, 5184		0·44195	0·41009	0·14796	S
107	Yale *12* I 5130, 5146, 5150		0·47127	0·32539	0·20334	W
108	Yale *16* 4911, 4917, 4923		0·61756	0·21084	0·17160	R

W. H. ROBERTSON.

TABLE II.—*Continued.*

	Comparison Stars.	Dependences.			
109	Yale *17* 4828, 4833, 4837	0·34835	0·28579	0·36586	W
110	Yale *11* 5190, 5191, 5198	0·33314	0·10231	0·56455	W
111	Yale *11* 5040, 5051, 5057	0·26199	0·51331	0·22470	R
112	Yale *14* 11088, 11093, 11108	0·15239	0·40973	0·43788	R
113	Yale *14* 13599, 13610, 13616	0·21396	0·46293	0·32311	S
114	Yale *13* II 12233, 12262, *14* 13056	0·20273	0·36564	0·43163	W
115	Yale *21* 3002, 3009, 3011	0·32658	0·45787	0·21555	S
116	Cord. C 7122, 7124, 7167	0·33656	0·44366	0·21978	S
117	Cord. C 6999, 7025, 7031	0·25892	0·28265	0·45843	R
118	Yale *16* 5814, 5824, 5826	0·13567	0·35063	0·51370	R
119	Yale *17* 5691, 5694, 5702	0·27417	0·31931	0·40653	S
120	Yale *12* 5493, 5510, 5523	0·36554	0·34382	0·29064	S
121	Yale *12* I 4736, 4738, 4759	0·24711	0·48826	0·26463	W
122	Yale *11* 156, 157, 166	0·17642	0·20424	0·61934	R
123	Yale *11* 88, 92, 108	0·22226	0·46008	0·31766	R
124	Yale *16* 4021, 4028, 4029	0·47104	0·29057	0·23839	S
125	Yale *12* I 5098, 5099, 5103	0·76200	0·15033	0·08767	R
126	Yale *11* 4626, 4628, 4643	0·38400	0·28470	0·33130	R
127	Yale *12* I 6396, 6403, 6421	0·38214	0·32111	0·29674	R
128	Yale *12* I 6245, 6252, 6272	0·43290	0·28243	0·28467	S
129	Yale *16* 4284, 4292, 4301	0·53589	0·34367	0·12044	S
130	Yale *17* 4238, 4250, 4256	0·42017	0·39887	0·18096	R
131	Cape Annals *17* 7988, 7989, 8013	0·24109	0·42742	0·33148	S
132	Cord. B 9310, Cape Annals *17* 7651, 7656	0·47943	0·29674	0·22382	W
133	Yale *14* 10423, 10434, 10437	0·39895	0·31348	0·28757	W
134	Yale *14* 10182, 10192, 10199	0·21178	0·46627	0·32195	S
135	Yale *12* I 4880, 4887, 4895	0·51909	0·24199	0·23892	S
136	Yale *11* 4506, 4511, 4529	0·32659	0·32550	0·34791	W
137	Yale *13* II 13611, 13626, 13638	0·30393	0·19441	0·50166	R
138	Yale *14* 13890, 13891, 13914	0·58256	0·20068	0·21676	R
139	Yale *14* 14553, 14560, 14581	0·18352	0·47193	0·34456	R
140	Yale *14* 14472, 14487, 14492	0·43862	0·22528	0·33610	W
141	Yale *16* 4372, 4381, 4389	0·59900	0·15819	0·24281	S
142	Yale *17* 4332, 4341, 4355	0·31791	0·24057	0·44152	S
143	Yale *12* I 8537, 8553, 8562	0·21913	0·24632	0·53455	R
144	Yale *12* II 9546, 9561, 9573	0·32994	0·26248	0·40757	W
145	Yale *14* 15873, 15884, 15899	0·37769	0·33816	0·28416	W
146	Yale *14* 15735, 15762, 15773	0·55735	0·20925	0·23340	W
147	Yale *11* 142, 149, 155	0·26750	0·20381	0·52869	W
148	Yale *11* 133, 149, 154	0·54680	0·14622	0·30698	R
149	Yale *12* I 125, 134, 141	0·42722	0·45539	0·11739	R
150	Yale *14* 13159, 13169, 13205	0·41559	0·33704	0·24737	S
151	Yale *14* 12713, 12734, 12754	0·39099	0·37438	0·23463	S
152	Yale *11* 4544, 4551, 4557	0·22347	0·25501	0·52151	S
153	Yale *11* 4477, 4481, 4487	0·37514	0·40425	0·22061	S
154	Yale *17* 713, 723, 726	0·17050	0·54538	0·28412	R
155	Yale *17* 713, 723, 726	0·35654	0·61496	0·02851	R
156	Yale *17* 586, 594, 610	0·35110	0·49029	0·15861	W
157	Yale *12* I 5718, 5731, 5735	—0·18797	—0·13643	1·32440	R
158	Yale *12* I 5649, 5659, 5669	0·34149	0·27097	0·38754	R
159	Yale *11* 5677, 5696, *16* 5695	0·48944	0·30007	0·21049	R
160	Yale *11* 5529, 5540, 5545	0·28807	0·08410	0·62783	S
161	Yale *12* I 5682, 5688, 5706	0·30947	0·52671	0·16382	R
162	Yale *12* I 5519, 5529, 5531	0·38649	0·30755	0·30596	R
163	Yale *17* 710, 726, 732	0·49488	—0·13170	0·63682	R
164	Yale *17* 712, 713, 732	0·28140	0·35538	0·36322	R
165	Yale *14* 13425, 13448, 13454	0·20166	0·51991	0·27843	R
166	Yale *14* 13299, 13308, 13323	0·37467	0·18080	0·44453	W
167	Yale *12* I 4735, 4742, 4751	0·21994	0·46186	0·31820	S
168	Yale *11* 4397, 4413, 4417	0·26899	0·37107	0·35994	W
169	Yale *14* 11161, 11186, 11201	0·39398	0·25865	0·34737	S
170	Yale *14* 10849, 10863, 10875	0·25938	0·36415	0·37648	W
171	Yale *11* 5951, 5953, 5971	0·10022	0·44666	0·45313	R
172	Yale *11* 5821, 5824, 5830	0·37914	0·24919	0·37166	W

TABLE II.—*Continued*.

	Comparison Stars.		Dependences.			
173	Yale *12* I 6375, 6394, 6399		0·10977	0·44037	0·44987	R
174	Yale *12* I 6339, 6350, 6370		0·38551	0·32752	0·28697	S
175	Yale *12* I 8765, 8769, 8779		0·42371	0·17310	0·40318	S
176	Yale *11* 8674, 8685, 8691		0·29813	0·39787	0·30400	S
177	Yale *14* 13169, 13214, 13219		0·24843	0·32186	0·42972	S
178	Yale *14* 12662, 12687, 12700		0·44644	0·16398	0·38958	W
179	Yale *17* 4036, 4044, 4056		0·21862	0·51661	0·26477	W
180	Yale *11* 457, 470, 480		0·22098	0·41385	0·36517	R
181	Yale *11* 391, 394, 408		0·40929	0·20884	0·38187	R
182	Yale *16* 8211, 8216, 8222		0·43469	0·19462	0·37069	S
183	Yale *11* 5082, 5090, 5100		0·41571	0·21211	0·37219	R
184	Yale *13* II 7673, 7693, 7705		0·17408	0·32628	0·49964	W
185	Yale *13* II 7567, 7584, 7603		0·16994	0·57881	0·25124	S
186	Yale *11* 4298, 4306, 4309		0·21643	0·27681	0·50676	R
187	Yale *11* 4236, 4251, 4256		0·49309	0·40500	0·10192	W
188	Yale *13* I 5200, 5206, 5210		0·38905	0·21228	0·39867	S
189	Yale *13* I 5083, 5107, *12* II 5098		0·21965	0·31981	0·46054	S
190	Yale *14* 997, 1007, 1011		0·39871	0·29547	0·30582	S
191	Yale *14* 774, 786, 798		0·39453	0·23876	0·36671	R
192	Yale *13* II 10191, 10208, 10221		0·30896	0·27448	0·41656	S
193	Yale *14* 11078, 11088, 11093		0·38788	0·33846	0·27366	R
194	Yale *16* 4790, 4802, 4810		0·31405	0·40570	0·28025	S
195	Yale *16* 4656, 4666, 4673		0·28302	0·62487	0·09211	R
196	Cord. C 10625, 10627, 10645		0·14064	0·43315	0·42620	S
197	Perth *6* 1585, Cord. C 10475, 10503		0·45384	0·13094	0·41521	R
198	Yale *12* II 8472, 8481, *13* I 8479		0·19970	0·12954	0·67076	R
199	Yale *13* I 8177, 8210, 8215		0·34439	0·33157	0·32404	W
200	Yale *14* 10222, 10233, 10246		0·31411	0·27582	0·41007	W
201	Yale *14* 9985, 9995, 10017		0·12838	0·58476	0·28687	R
202	Cord. C 8807, 8808, GC 22119		0·36325	0·37491	0·26184	R
203	Cape Annals *17* 8122, 8144, 8168		0·20284	0·35319	0·44397	R
204	Yale *11* 8074, 8083, 8101		0·57431	0·16187	0·26382	S
205	Yale *16* 8121, 8129, 8141		0·26202	0·25231	0·48567	S
206	Yale *12* I 5394, 5398, 5400		0·29725	0·30748	0·39526	R
207	Yale *16* 8410, 8412, 8414		0·48133	0·31871	0·19996	R
208	Yale *16* 8271, 8283, 8297		0·23866	0·28504	0·47630	R
209	Yale *16* 4546, 4551, 4566		0·57164	0·32136	0·10700	R
210	Yale *16* 4429, 4433, 4447		0·22586	0·23273	0·54140	S
211	Cape Annals *17* 9397, 9398, 9416		0·27545	0·51095	0·21359	R˙
212	Cape Annals *17* 9233, 9245, 9250		0·41955	0·15033	0·43012	R
213	Yale *14* 15758, 15762, 15780		0·62002	0·09045	0·28953	W
214	Yale *13* II 14853, 14883, *14* 15645		0·24290	0·51272	0·24438	W
215	Cape Annals *17* 10160, 10163, 10176		0·13650	0·20899	0·65451	R
216	Yale *14* 11026, 11058, 11073		0·27816	0·36496	0·35688	S
217	Yale *14* 10834, 10843, 10864		0·50774	0·18675	0·30551	W
218	Yale *14* 12572, 12589, 12597		0·11496	0·36563	0·51940	R
219	Yale *14* 12497, 12499, 12525		0·53542	0·09611	0·36847	S
220	Yale *12* I 4899, 4923, 4924		0·39595	0·28050	0·32354	W
221	Yale *12* I 4822, 4834, 4841		0·09372	0·64780	0·25848	W
222	Yale *12* I 5370, 5394, 5396		0·38503	0·17146	0·44352	R
223	Yale *14* 10864, 10867, 10884		0·20141	0·44958	0·34902	W
224	Yale *12* II 9264, 9276, 9288		0·24438	0·53251	0·22311	W
225	Yale *13* I 9151, 9157, 9161		0·28174	0·56871	0·14955	W
226	Yale *12* I 221, 223, 231		0·44938	0·13291	0·41771	S
227	Yale *12* I 8156, 8164, 8169		0·04859	0·40394	0·54746	W
228	Yale *12* II 9206, 9226, *12* I 8128		0·23693	0·41229	0·35078	R
229	Yale *12* II 9183, 9184, 9203		0·34306	0·39230	0·26464	S
230	Yale *12* II 9153, 9162, *12* I 8071		0·49838	0·32703	0·17459	W

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CLARKE MEMORIAL LECTURE*

SOME ASPECTS OF NEW SOUTH WALES GEMSTONES.

By R. O. Chalmers, a.s.t.c.

The Australian Museum, Sydney.

With four text-figures.

In acknowledging the honour the Council of the Royal Society of New South Wales has conferred upon me in inviting me to deliver the Clarke Memorial Lecture, I would express the hope that, as well as placing before you a somewhat specialized subject, I may also be able to convey to you something of Clarke's versatility in geological science. Because of public interest and demand in the 1860's he perforce had to turn from geology, somewhat unwillingly at times one suspects, to mineralogy and devoted considerable attention to the gemstones of New South Wales, particularly diamonds. Clarke (1870) in his Anniversary Address to this Society, states that thousands of gemstones were being submitted to him for identification and that at times he was almost overwhelmed with letters and visitors on the subject. He was scathing about the treated fragments of bottle stoppers and other glass objects sent in at times. He evidently considered that this was done intentionally because he speaks of " the glass grinders who were sometimes more transparent than the material they manipulated ", in contradistinction to the many genuine diggers who were merely mistaken and not impostors.

Clarke himself was not optimistic about the future of the gemstone industry in New South Wales. Although at the time of his death in 1878 few of our gemstone resources were known it must be made clear that, despite the variety and interest of our gemstones, no large or lucrative industry has been established. His advice to intending diamond prospectors might well serve for any prospector at any time. It is as follows—" Without wishing to dishearten any diligent man who, while anxious to serve himself, is doing his utmost to develop the resources of the country, it is surely right to warn any who have only their personal labour and privations to look to, against embarking in a search which to be successful requires ample means and union of energies and machinery " (1870). Also when informed of a discovery of sapphires near Armidale he remarked " I think our friends in New England would do better to seek for tin lodes " (1869).

On the other hand it is to be remembered that because gemstone mining was invariably carried out by individuals or small parties, an understandable secretiveness developed and official Mines Department statistics always underestimate the true output. It is intended now to present a systematic account of New South Wales gemstones providing a brief summary of accumulated knowledge up to the present and in addition draw attention to new discoveries that have come to light since the valuable contributions of Liversidge (1888), Curran (1896), Pittman (1901) and Smith (1926).

Numbers prefixed by the letter D: are the registered numbers of Australian Museum specimens.

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* Delivered to the Royal Society of New South Wales, June 16, 1955.

DIAMOND.

Localities. Diamonds have been found in numerous localities in New South Wales. Although mention had been made of diamonds by Hargraves (1851) and Stutchbury (1851) the first reliable identifications were made by Clarke (1860) who recorded and described six undoubted diamonds that had been brought to him ; four from Suttor's Bar on the Macquarie River, one from the mouth of Pyramul Creek and one from Calula Creek. Clarke was also the first to mention diamonds from Bingara.

The three most important diamond fields were discovered in rapid succession soon after. In 1867 a gold rush to Two Mile Flat on the Cudgegong River some 19 miles north-west of Mudgee led to the discovery of diamonds. They occurred in isolated patches of an ancient river drift, Pliocene in age. These ancient drifts known as deep leads were found 40 feet above the present bed of the Cudgegong River. This phase of the operations ended in 1870. Operations were resumed for a year in 1916 with small returns.

The Bingara Field about 5 miles west south west of Bingara was discovered in 1872 and fully reported on and mapped by Anderson (1887). The diamond bearing gravels as at Two Mile Flat are Pliocene in age. Work on the field flagged considerably in 1873 because there was little interest in the stones on account of their smallness and unsuitability for jewellery. Small scale production was resumed mainly on the Monte Christo claim, and continued for some years but seems finally to have ceased in 1904.

Wilkinson (1875) made the first mention of Copeton or Boggy Camp, the most important field. Unlike Cudgegong and Bingara, diamonds were first found in recent alluvial deposits by tin miners. Subsequently it was discovered that they had been washed from nearby Pliocene stream gravels, which are frequently basalt capped and are the main source of the diamonds. As one would expect in these deep leads the alluvial deposits fall naturally into four zones, the bottom one consisting of coarse gravels known as the wash containing the bulk of the diamonds ; secondly the medium sized sands and gravels known as the drift which constituted the main bulk of the deposits ; thirdly, fine mud and clay, and lastly a deposit of vegetable debris on top. Sometimes the wash is so indurated by a ferruginous cement that crushing cannot be undertaken for fear of shattering the diamonds. For example at Staggy Creek and Malacca two of the diamond localities near Copeton the wash consisting of waterworn quartz, feldspar fragments, and black tourmaline is exceedingly firmly consolidated in a hard ferruginous matrix. On the other hand less ferruginous and more friable examples of the wash are known, as at Round Mount.

Anderson (1887) first mapped the sporadic deposits of diamond bearing wash and later Cotton (1914) modified and amplified this work and traced two branches of an ancient river for some 14 miles in all which in former times had flowed in a northerly direction towards Inverell, thus disproving a contention of previous workers that since Copeton diamonds are bigger than Bingara diamonds the main Tertiary stream must have flowed west from Copeton to Bingara. Production of diamonds at Copeton dwindled markedly after 1904 then again after 1922, and excepting a small resurgence during the War when African diamonds were scarce, has gradually become negligible.

Diamonds have been discovered and mentioned in other parts of New South Wales. At no great distances from Copeton diamonds have been found on Bora Creek and at Tingha. Wilkinson (1876) mentions the occurrence at Muckerawa near Stuart Town. Liversidge (1888) reported them from Oberon, Trunkey, the Lachlan River, the Abercrombie River and various localities in the Hill End district. A few stones were found in an alluvial deposit on Mount

MacDonald, near the Lachlan River some 16 miles east of Cowra (McLachlan, 1901). In the collection of the Australian Museum are three diamonds (D :34593) two of them yellow, from the " upper Lachlan River ". A few diamonds have been mentioned from the Crookwell River. Two localities aroused more than passing interest some fifty years ago. These were certain areas in the vicinity of Mittagong (Curran, 1896) and Mount Werong (Pittman, 1905). A diamond weighing $28\frac{5}{16}$ carats was stated to have been found at this latter locality and the stone was actually identified and inspected by the Mines Department. A certain amount of mining was done in each place for a short while. It seems however that nothing further was reported after the initial discoveries so that there are good grounds for suspecting that the diamonds produced as evidence did not actually come from these localities.

Text-fig. 1.—Diamond localities on or near the Macquarie, Cudgegong and Turon Rivers and their tributaries. (X) marks Calula Creek from which Clarke identified a diamond from an indefinite locality.

One very interesting feature of recent years has been the recovery of diamonds by Wellington Alluvials Ltd., in their gold dredge on the Macquarie River some ten miles south-east of Wellington. This is the only locality in New South Wales for some years whose yield of diamonds has been of any economic significance. Starting with a production of 130 carats in 1950 the figure for 1954 up to the end of September was 1301 carats. There are two types of stones. A hard " Australian type " diamond corresponding to those from Copeton and a softer diamond, equivalent in hardness to the South African stones. The hard types show no particular crystal shape. Of the stones showing crystal shape the commonest forms are octahedra and flattened octahedral twins. Some show very sharp edges and corners and probably originate near Wellington. The stones range from straw to clear blue-white, all intermediate shades being represented. They are associated with plentiful corundums of no commercial value. The diamonds are essentially industrial

stones but about 5% can be cut as gemstones.   It is of interest to note that
the present site of this dredging is quite near Suttor's Bar, one of the localities
from which Clarke originally recorded diamonds.   Those localities already
mentioned on or near the Macquarie, Cudgegong and Turon Rivers no doubt
have contributed to the concentration of diamonds now being worked.

Origin.   Considerable interest in the past has been evinced concerning the
origin of the diamond in New South Wales.   Taylor and Thompson (1870) in
their description of the Cudgegong field expressed the view that the diamond
had originated in the ancient drift itself.   This seems to have been based on
the following evidence—1. Diamonds are only found in the present bed of the
Cudgegong where gold diggers had previously discharged the older Pliocene
drift into the river. 2. The diamonds are never waterworn whereas the
associated gemstones are.   3. The diamonds are not uniformly distributed in
the drift as the other gems but generally occur in rich patches.   Clarke (1870)
seems to have given this view some credence stating " . . . infiltration,
decomposition and reconstruction of carbonaceous materials of whatever age
under the influence of chemical transformation may be producing diamonds at
this moment where the needful conditions exist."   Originally Wilkinson (1887)
subscribed to this view but after having personally examined the Copeton
occurrence he came to the conclusion that the diamonds had originated in the
nearby metamorphosed Palæozoic sediments.

In 1870 diamonds were discovered in a basic igneous rock forming the
filling of volcanic necks at Kimberley, Orange Free State, South Africa.   This
notable discovery strengthened the belief that perhaps basic and ultrabasic
rocks might be the original source of the diamond in other parts of the world.
Twelve miles south of Bingara at Ruby Hill, a volcanic pipe containing fragments
of breccia was described by Pittman (1901) and Card (1902).   In 1889 a few
diamonds were supposed to have been recovered from the breccia.   Interest
became keener when eclogite fragments were identified later on because shortly
before, Bonney (1900) in England had described small diamonds embedded in a
fragment of eclogite one of the constituents of the volcanic breccia in South
Africa.   No further finds of diamonds, however, were made at Ruby Hill.

In 1904 Messrs. Pike and O'Donnell were prospecting a basalt covered
deep lead at Oakey Creek on the Copeton field.   While driving a tunnel under
the basalt, three dykes of decomposed dolerite were encountered.   In those
parts of the nearby wash which were richest in diamonds an abundance of
dolerite fragments were found.   Subsequently a diamond was discovered
embedded in solid dolerite.   Pittman (1904) stated that it was embedded to
the extent of two-thirds of its bulk.   It was also stated that another diamond
was found in a heap of dolerite that had weathered in the open and that
indentations on the surface of this second diamond contained fresh dolerite.
A good deal was written on this discovery by Pike and David in various news-
papers at the time.   It was taken abroad by David (1906a, 1906b) and shown
to various eminent geologists at the British Association for the Advancement
of Science meeting and the International Geological Congress meeting in Mexico,
none of whom had any doubts about its authenticity.   Cotton (1914) was also
convinced of the genuineness of the specimen.   These are the facts connected
with this discovery and while it must be admitted that general doubts are
expressed by geologists and mineralogists at the present day, this may be because
of the entire absence of confirmatory evidence following the initial discovery.

Associated Minerals, Quality and Size.   In the deep leads diamonds are
associated with waterworn fragments of other minerals such as pleonaste, topaz,
quartz, zircon, black tourmaline, garnet, cassiterite, spinel and rarely sapphire.
Various colours have been noted.   The most common colour is a not very

pronounced yellow, actually an off-colour. Sometimes they are a pronounced yellow. Porter (1898) recorded purest white, black, bronze, blue tint, green tint, rose, deep and light orange, lemon and straw. It was stated by Davies and Etheridge (1886) that defects such as " black specks ", " cleavage ", macles (or twinned xls) and " flats " were found less often than in Cape diamonds. This meant that in general New South Wales stones were of good quality. However they were generally small. Although it was stated that one 5⅝ carat stone was found at Cudgegong, over the whole field the average number to the carat was four stones.   At Bingara the average was five per carat and in places the stones were so small that the average per carat was 20.   The Copeton stones in general were larger, frequently averaging three per carat.   T. Heath of Copeton in a personal communication states that the largest diamond was an eight carat fractured white.   He also mentions a 12 carat piece of bort. However, on account of their superior hardness they came to be sought mainly for industrial purposes.   Relatively few gems have been cut and these mainly in the early days of production.

Hardness. Atkinson (1886) first stated that New South Wales diamonds were harder to cut than those from elsewhere. This was apparently noticed as stones from Bingara first reached the London market. This report did not state whether the difficulty was encountered in sawing or grinding. This has been generally accepted as a fact and some confirmation of their superior hardness has come from the experience of Australian industry during the war. (Chalmers, 1946).   One cannot be absolutely definite on the basis of such general statements, because hardness in diamond is a vector property, that is it varies with direction and no properly designed experiments based on rate of cutting and grinding or on the degree of micro-indentation have been carried out on New South Wales diamonds.   One reads contradictory statements in literature. Kraus and Slawson (1939) state generally that it is impossible to cut, grind or polish diamond in a direction parallel to the octahedron faces.   On the other hand Grodzinski (1952) has found it extremely difficult to saw New South Wales diamonds in a direction parallel to the cube face, yet in abrasion tests on ordinary scaifes approximately in a cube plane these diamonds were no more resistant than Brazilian stones.   He expresses the opinion that the greater resistance of New South Wales stones may be because they are full of small " naats " (knots) which owing to their different orientation may hinder the polishing action.

OPAL

Prior to the discovery of the extensive fields of Queensland, New South Wales and South Australia, isolated occurrences of precious opal in small areas were known only from Czechoslovakia (formerly Hungary), Mexico and Honduras. For many centuries dating back to the time of the Romans it was known only from Hungary and was highly prized. All these occurrences are in igneous rocks.

Localities. In New South Wales there are three isolated occurrences of precious opal in igneous rocks. The opal deposit seven miles west of Trunkey on Rocky Bridge Creek a tributary of the Abercrombie River, was reported on by Wilkinson (1877) who stated that the matrix was a soft decomposed vesicular basalt, and by Curran (1896) who regarded it as an acidic or andesitic lava. H. F. Whitworth informs me that specimens in the Mining Museum examined by Card are certainly olivine poor Tertiary basalt. L. J. Lawrence has shown me a specimen in which light coloured common opal, showing occasional play of colour fills vesicles averaging 5mm. in length, in a light grey friable rock which, though very decomposed, in thin section is seen to be a basalt.   Obviously it can be said that the matrix is variable.   The field is of no economic significance.

Pittman (1907) noted the occurrence of precious opal filling vesicles in trachyte at Tooraweanah, Warrumbungle Mountains.

In 1901 opal from Tintenbar, five miles north-west of Ballina was first noted but it was not until 1919 that the field was discovered to have serious possibilities. Precious opal occurs in cavities in a decomposed basalt and also as pieces varying in size from a pea to a large walnut, loose in the soil where they have been detached from the parent rock by weathering (Morrison, 1919). In Tintenbar opal the colours stand out in a transparent matrix but the marked tendency of the stone to craze, before very long led to the cessation of all work on the field.

In the principal opal fields of New South Wales the occurrence is quite different and of a type noted nowhere else in the world. It occurs in sediments of lower Cretaceous age and is unconnected with any igneous activity. All these sedimentary occurrences whether in Queensland, New South Wales or South Australia have certain features in common. The opal deposits are found dominantly in beds of clayey sandstone always in arid or semi-arid regions in plain country broken only by low flat topped hills. The deposits are seldom found at depths below the surface exceeding 100 feet. It might be mentioned in passing that the matrix of Queensland opal differs from that of the other two states due no doubt to the fact that in Queensland the age of the host rocks is Eyrian (Early Tertiary). These overlie the Cretaceous rocks unconformably. A most notable feature of opal, is that unlike most other gemstone occurrences these opaliferous sediments extend over vast distances. Known opal deposits in New South Wales occur over an area of some 2,000 square miles but of course not all of the opal is the precious variety.

At White Cliffs, where opal was first discovered in 1889, a thin bedded fine grained siliceous sandstone occurring at depths of from 25 to 40 feet below the surface is the important marker horizon although it carries no opal. This " bandstone " as it is called is both underlain and overlain by a fine grained clayey sandstone. In the underlying beds the greatest abundance of opal is found. The precious opal is found in thin veins of potch or common opal. It is distributed quite irregularly within the potch horizons which follow the bedding planes of the sandstone and also fill joints. Precious opal also is found replacing the fossil fauna of the Cretaceous sediments. Invertebrate forms thus completely replaced include molluscs (both pelecypods and brachiopods), crinoids, belemnites, the internal skeleton of Cretaceous cuttle-fish and vertebrate remains such as teeth, ribs and limb bones of *Cimiliosaurus* a small form of the well known Plesiosaurus, a marine reptile equipped with paddle-like limbs as a means of propulsion. Opalized wood is also found.

Opal pseudomorphous after other minerals also occurs, the best known examples being the well known opal " pineapples " in which the opal has replaced the mineral glauberite (Anderson and Jevons, 1905).

At Lightning Ridge, originally known as Wallangulla, most noted for black opal, at which organized mining began in 1903, the host rock is the same as at White Cliffs but here there are four separate levels of the silicified " bandstone " and beneath each one is the white clayey sandstone containing the precious opal. Here, instead of occurring as seams and joint fillings, as at White Cliffs, it is found principally as isolated nodules known as " nobbies ". These are usually most abundant near the roof of each " level " of the host rock, known to the miner as opal dirt. Many of these nobbies have the form of a miniature volcanic peak and show well marked striations. O. le M. Knight (personal communication) expresses the opinion that these were called " nobbies " by the miners because of this prominence or " nob ". One gets the strong impression that these are replacements of organic forms but no suggestion has yet been

made by palæontologists as to what the original form might have been.   In some parts of the field, shafts have been sunk as deep as 90 feet.

White Cliffs and Lightning Ridge are the only two New South Wales opal fields of importance.   With these must be included their logical extensions such as Purnanga some 40 miles north of White Cliffs and Grawin some 29 miles south west of Lightning Ridge.   However, Lower Cretaceous sediments cover large areas in the north-west of the state.   Traces of precious opal have been recorded in outlying parts of the state such as at Milparinka (Slee, 1895).   The Australian Museum has in its collection opal specimens from Brindingabba near Hungerford on the Queensland border.   All this evidence suggests that careful prospecting might disclose other opal bearing areas in the state.

Mode of Formation.   Under the climatic conditions prevailing in Lower and Middle Miocene time in the Tertiary, widespread lateritization took place in Australia particularly in the inland parts of the continent.   Much silica was released in the process.   The most marked climatic feature was the alternation of tropical wet and dry seasons.   In the wet periods the water table was lowered and because it was an era of almost perfect peneplanation and consequent poor drainage, the groudwater remained in constant contact with the underlying rocks and exercised its maximum solvent action.   In the dry periods capillary action brought dissolved silica and other substances to the surface where they were deposited and replaced other rocks to form the dense hard siliceous deposits named the duricrust by Woolnough and popularly known as " grey billy " or " billy ", that cover vast areas of inland Australia.   This was originally thought to be of Cretaceous Age and was called the Desert Sandstone, but is now considered to have formed in the Miocene.   An admirable summary of these matters is given by Kenny (1934).

During the passage to the surface of these solutions, silica in colloidal form, that is silica gel, was deposited in favourable environments in the Cretaceous or Tertiary sediments through which they passed.   This eventually consolidated to form opal.   There is no direct evidence of what caused the formation of the silica gel in nature.   Kenny (1934) has suggested that the original clay content of the replaced rocks may have dissociated into bauxite and opaline silica, or that the clay may have acted as a precipitating agent for silica.   Leechman (1951a) has pointed out that on the basis of the great number of experiments that have been carried out by various workers on the formation and nature of silicic acid gels it could have been due to the ascending solutions of silicates in the groundwater coming into contact with descending acidic solutions.   Dwyer and Mellor (1934) as result of X-ray studies of the structure of opal have shown that opal formed from groundwaters such as White Cliffs and Lightning Ridge have not been subjected to heat during their geological history so that it can be assumed that all solutions involved were of a low temperature type.

Solidification of the silica gel then took place as evaporation proceeded, but the greater part of the opal so formed is " potch " or common opal. Leechman (1951a) has dealt very fully with the influence that the nature and concentration of solutions has on the formation of common opal and those types of " potch " that show the first traces of colour patches.   Here we are only concerned with precious opal that shows the well known brilliant play of colours.   It can be said with certainty that a very long period of gelation is required to give time for incipient crystallization to begin within the gel.

Play of Colours.   There is a long standing belief that opal is amorphous i.e. lacks any trace of internal crystalline structure.   This statement is still found in text books and is still taught to students.   However, as long ago as twenty years, X-ray studies by Levin and Ott (1932, 1933), and Dwyer and Mellor (1932) showed that opals contain crystallites of cristabolite one of the

naturally occurring forms of silica.   It is also still stated that the play of colours in opal are interference colours caused by the presence of minute cracks within the opal that developed during the contraction of the gel as it solidified. Leechman (1951b, 1954) pointed out that whereas interference colours are a mixture of various colours in the spectrum which remain when one particular component colour is eliminated, the colours of an opal are monochromatic that is, they are pure single colours not mixtures of colour, which suggests that they are due to white light being broken up into its component colours. Raman and Jayaraman (1953) have shown by X-ray examination that, as Leechman had already suggested, the key to the explanation of the cause of the colours is the finely stratified nature of crystalline structures within the opal. They have shown that these structures consist of alternate layers of two crystalline modifications of silica of slightly different refractive indices. These modifications are low-tridymite and high-cristobalite.   Spectroscopic examination of the play of colours reflected from these stratified structures prove them to be pure monochromatic hues, and therefore not caused by interference.   It is pointed out that the high degree of perfection of the reflections from opal show that the alternate layers occur in great numbers and are spaced regularly, the magnitude of the spacing being of the same order as the wave length of light.   The magnitude of the spacing indeed corresponds more to the smaller wave lengths of light which explains why the smaller wave length colours, violet, blue and green are seen more frequently than the higher wave length colours, red and orange.   One of the most convincing proofs that the colours of opal are caused by the inherent structure of the mineral was first afforded by Dwyer and Mellor (1932) who found that heating opal at 1000°C for eight hours did not destroy the colours.   Raman and Jayaraman proved this also by heating opal to such an extent that it disintegrated and yet the colours were not destroyed.

Unfortunately Raman and Jayaraman are not very explicit about the localities of the opal specimens examined.   Dwyer and Mellor (1932) found that a very definite X-ray pattern due to high-cristobalite was found in New South Wales opal of volcanic origin from Rocky Bridge Creek and Tintenbar.   This indicates a higher temperature of formation than in those from groundwater solutions, as one would expect.   However, there is no doubt that crystalline structures do exist in the latter type as well, even if more rudimentary.   Raman and Jayaraman have stated that because of the diffuseness of the X-ray patterns in gem opal, and one assumes he is speaking of our Australian opal formed from ground waters, the task of identifying the layered tridymite-cristobalite structures is more difficult.

It is thus clear that before opal can form, a number of highly critical conditions have to be fulfilled and hence noble opal takes its place amongst the precious stones because of its comparative rarity, even though it may lack durability.

It is not intended to deal with the history of the New South Wales fields. The fascination of opal has given rise to popular informative books on the subject to which the reader is referred (Wollaston, 1924, and Murphy, 1948).   Croll (1950) deals with the history, economic aspects and marketing.   A good account of the history of Lightning Ridge with a detailed map is given by Knight (1953).

SAPPHIRE.

Stutchbury (1851) mentioned sapphire from the Cudgegong River.   Clarke (1853) mentioned sapphire (including the green variety) as occurring generally in New England particularly in Tilbuster Creek.   The numerous localities from where sapphire has been noted in New South Wales are listed by Liversidge (1888), Curran (1896) and Pittman (1901).   As in the case of diamond, sapphires

are found either in deep leads of Tertiary age frequently capped by basalt, or in recent deposits derived from the denudation of the Tertiary leads. The most important locality is Sapphire, in the New England district some 15 miles north-east of Inverell. Other important localities are Bingara, Cope's Creek, Dundee, Glen Elgin, Gwydir River, Nundle, Peel River, Oban, Puddledock, Emmaville, Tingha, Abercrombie River, Two Mile Flat, Oberon and Mount Werong.

The first commercial mining seems to have been undertaken by C. L. Smith on his property at Argyle, near Sapphire in 1919 (Cambage, 1919). Prior to this, however, occasional stones had been sent out for cutting by such enthusiastic and discerning collectors of minerals and gemstones as the late D. A. Porter and the late George Smith. The principal sapphire bearing ground has been proved for a distance of one mile along a dry stream bed. They are found on the surface and down to a depth of three feet to four feet the average thickness of payable dirt being 18 inches to two feet. It is probably that most of the material has been redistributed by the erosion of Tertiary deep leads. Associated gem minerals at Sapphire are pleonaste and yellowish-brown to colourless zircons. Zircons are the most common associated minerals from all New England localities.

An early report of Curran's that a sapphire had been found embedded in basalt has been substantiated by other discoveries but there is always the possibility that they may have been caught up by molten basalt flows the eruption of which was later than the formation of the deep leads.

As Pittman has pointed out sapphire of first class gem quality occurs but rarely in New South Wales. Pure blue stones have generally such a deep tint that they appear almost opaque when cut. At Sapphire in addition to dark blue stones, parti-coloured blue and green, blue and yellow, and green and yellow stones are found. Quite attractive golden yellow stones are also found. Some bluish green stones in the collection of the Australian Museum collection were not entirely clear but had rather a misty appearance. A number of stones from Reddistone Creek, eight miles west of Glen Innes were examined and had the same general characteristics as the stones from Sapphire. A cursory microscopic examination of the small number of cut stones available showed such features as minute vesicular inclusions symmetrically arranged, hair-like crystals of rutile and colour banding, but further work would have to be done before any of these could be established as positive diagnostic characteristics for New South Wales stones.

While most sapphire come from the New England district there are other localities mentioned by Liversidge (1888) and Curran (1896), such as Tumberumba and Wingecarribee River.

Curran made special mention of opaque to translucent bronze coloured chatoyant corundum at Wingecarribee. In recent years material of this type from Anakie, Queensland, which when cut provides black star sapphires, has aroused a great deal of interest in America. It is interesting therefore to note that such material occurs not only at Wingecarribee but at practically every locality where gem-quality transparent sapphire occurs in New South Wales. Recently a large flattened piece of opaque blackish-bronze chatoyant corundum weighing 1149 carats ($7\frac{1}{3}$ oz.) was acquired by A. W. Rouse, a Sydney gemmologist. The exact locality has not been disclosed but it is definitely from New South Wales. This stone can be divided into three areas from each of which there is a possibility of cutting a large black star sapphire.

Ruby and Spinel

Ruby from Two Mile Flat was analyzed by Thomson, the result being given by Liversidge (1888), but in the absence of specific data it is impossible to vouch

for the correctness of the numerous references by earlier workers to these two gemstones.

No cut rubies from New South Wales are known to the writer. The occasional small waterworn fragments of pale pink transparent corundum that occur in gem gravels from localities such as Tumberumba—Jingellic (D:27773) and Burmah (Heiser's Mine), Sapphire (D:27772) are not true ruby. Fluorescence and specific gravity tests show it to be pink corundum. Small red octahedra of spinel mentioned by Smith (1926) are associated with the pink corundum fragments from these two localities and their identity has been confirmed by specific gravity tests. It seems certain that much of the material from the stream gravels stated in the past to have been spinel or ruby is actually garnet or zircon.

Beryl and Emerald

Beryl is a widespread mineral in the Emmaville and Torrington districts where it occurs in pegmatites associated with bismuth, wolframite, cassiterite, monazite, uranium minerals, quartz, feldspar and mica. The occurrence of beryl with special reference to gem material has been described by Smith (1926). The most transparent crystals were discovered associated with quartz, feldspar and mica at Heffernan's Wolfram Mine, three miles west of Torrington. Some fine pale yellowish green cut stones from this locality are in the collection of the Australian Museum. The largest (D:27793) weighs 73 carats and is remarkably free from flaws. Another deep green cut stone (D:15571) in this collection, though somewhat flawed, weighs 88·5 carats. It came from the Emmaville district. Waterworn-beryls are found in stream gravels in the New England district. Because of the columnar nature of the original crystals the waterworn pebbles have an elongated form. There is one crystal of gem quality golden beryl (D:31706) in the collection from Emmaville. There has never been commercial mining of beryl for gemstone purposes in New South Wales, but a short lived emerald industry on a very small scale was embarked upon in the Emmaville district some sixty-five years ago. The emeralds were first recognized by D. A. Porter in 1890, the locality being a tin mine known as de Milhou's Reef, M. L. 90, Ph. Wellington North, Co. Gough, 5 miles 70 chains, 12° east of north of Emmaville.

Small emerald crystals were noted in pockets which occurred at intervals in a dipping quartzose vein. Associated minerals were cassiterite, topaz, fluorite, arsenopyrite and quartz. The vein was mined in an endeavour to find these pockets at depth. A full description was given by David (1891). Three small scale ventures were attempted between 1890 and 1909 but only a few miners were employed at any one time. New South Wales emeralds are somewhat pale, compared to stones from Siberia, Colombia and South Africa. Under the Chelsea Filter they were pink, but a much paler tint than emeralds from these other localities. Tests with Clerici's solution showed the specific gravity to be less than that of Colombian emerald. The refractive index of New South Wales emeralds is 1·575 which is lower than that of Siberian and South African stones determined for comparison. The general rule is that pale emeralds, no matter what the locality, have slightly lower density and refractive index than deep coloured stones.

Topaz.

An early reference to topaz (Paterson, 1811) is so vague as to be valueless and so ambiguous that it seems likely that the specimens came from Port Dalrymple (Launceston) and not from New South Wales. Stutchbury (1851, 1853) recorded topaz from the Cudgegong and Castlereagh Rivers.

Like beryl, topaz is found either in situ or as waterworn fragments in the Emmaville-Torrington districts. It is found in pegmatites associated with granite intrusions. Associated minerals *in situ* are bismuth, fluorite, cassiterite, arsenopyrite, beryl and emerald. The most notable occurrence is in the stream gravels of the Oban River, Mitchell River and Nowlands Creek forming an area of considerable extent lying to the east of Guyra and Ben Lomond. This occurrence with special reference to gem material has been described by Smith (1926). While no steady mining of topaz seems to have been carried on, its interest as a gemstone was recognized. Sixty ounces of topaz were recorded as having been won presumably in conjunction with tin-mining (McLachlan, 1899). There is a popular erroneous belief that all topaz is yellow and the fact that this misconception still prevails is an indication that our own magnificent Oban topaz is not nearly well enough known. Oban topaz is mostly light blue, brilliant and absolutely flawless, and large waterworn pebbles and crystals have yielded some superb stones of unusually large size. It may also be colourless and sometimes has a faint pinkish brown tint. The largest cut stone
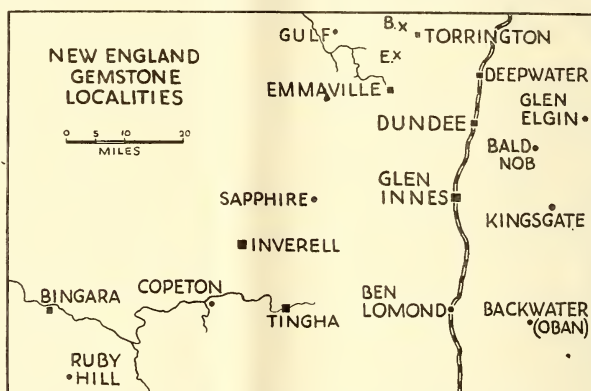
Text-fig. 2.—Gemstone localities in the northern part of New England. B.X is the beryl's locality at Heffernan's Mine and E.X is the emerald locality. Oban, which is actually a district, is shown only by the nearest post-office, Backwater.

in the Australian Museum is a superb specimen (D:15768) weighing 184 carats (1·2 oz.). The largest crystal in the Museum collection (D:38854) weighs $1\frac{1}{2}$ lb. It is a pronounced blue colour, and is only part of a large crystal stated to have come from Kerrabee, on the Goulburn River, 20 miles south of Merriwa but this is unlikely to be its original source. It may conceivably have come from Mudgee or Gulgong. Liversidge (1888) mentions portion of a blue-green crystal from Mudgee weighing several pounds, in the Melbourne Technological Museum, and two others of the same colour, one weighing 11oz. from Gundagai and the other from Gulgong weighing 1lb. 2oz. There is no detailed description of these occurrences in literature, and the fact that such outstanding specimens were once found at these localities is almost forgotten. Pale blue topaz under short-wave ultra-violet rays occasionally fluoresces a faint, patchy pale yellowish green.

ZIRCON AND GARNET.

Zircon is particularly abundant in the gem gravels of the New England district. The following observations have been made on material in the Australian Museum collection. From Nundle the prevailing colour is yellowish brown ranging from very pale to very deep shades. Prisms and pyramids are seen on crystal fragments, but no marked cleavages are apparent. All

zircons from this locality fluoresce yellow under a short-wave ultra-violet lamp. The fainter the colour the brighter yellow and more luminous the fluorescence. The darker the stone the more dull and patchy the fluorescence becomes. Many waterworn fragments from more northern New England localities, Rocky River, Uralla, Bald Nob, Sapphire, and Inverell were also examined. Three principal colour varieties occur in each of these localities, deep red or deep reddish brown, brownish pink, and colourless to faint yellow. There is a gradation in colour from the deep red to brownish pink. The pale yellow to colourless varieties, under a short-wave ultra-violet lamp, fluoresce bright luminous yellow. The brownish pink stones fluoresce a golden brown, dull and patchy in appearance. The red stones do not fluoresce at all. The pale yellow to colourless varieties, predominate in material from Inverell. These frequently occur as slightly waterworn crystals showing prisms and pyramids. At times perfect basal and prismatic cleavages can be seen. Deep red to reddish brown varieties predominate in material from the Rocky River, Uralla, and in crystal fragments pyramids are the most prominent faces. A perfect basal cleavage and an imperfect prismatic cleavage are sometimes seen. All of these varieties showing the same types of fluorescence have been noted in gem gravels from Berrima and Trunkey. These zircon concentrates are obtained from streambeds, while washing for alluvial cassiterite, and the greater portion of them consist of fragments too small to cut as gemstones, but an occasional most attractive cut red or yellowish brown zircon from New South Wales is seen. The largest waterworn fragments (D:27764) each weighing 10 to 30 carats are from 12 miles south-east of Oban. They are dark red. Two contributing factors to the abundance of zircon are that it is a mineral of high specific gravity and would stay behind in the wash, and also it is a very stable mineral not subject to alteration. Other localities for zircon in the New England district are given by Porter (1888) and Smith (1926).

A few quite attractive cut stones of the garnet varieties almandine, pyrope and essonite in the Australian Museum collection, all come from Oban. Both Porter (1894) and Curran (1896) have mentioned a locality 12 miles form Bingera on the Tamworth road, from which good pyrope garnets were cut. New England pyropes closely resemble the red zircons, and can easily be mistaken for them unless confirmatory tests are carried out. The occurrence of gem quality almandine in the Barrier Ranges seems to have first been recorded by Wilkinson (1887) who mentions it as occurring at Poolamacca, Corona and Silverton.

QUARTZ.

Smith (1926) has dealt fully with quartz occurrences, particularly in the New England district and much of this material would no doubt prove suitable for gemstones. Except where otherwise mentioned reference herein is made only to specimens in the Australian Museum collection.

Rock Crystal. Spectacular clear large crystals of quartz have been found in the past in various mines at Kingsgate, associated principally with bismuth and molybdenite. Miss F. S. Sachs, of the Australian Museum, formerly resident at Kingsgate remembers a 25lb. crystal of perfectly clear quartz from the Arsenic Shaft. She still has in her possession a clear flawless mass weighing nearly 2lb. from this shaft. While material of this quality would be eminently suitable for gemstones, no cut stones from this locality are in the Museum collection. The largest cut stone is from Oban and weighs 188 carats (1·2 oz.).

Fine groups of flawless transparent crystals come from the Conrad Mine, Howell and from Nundle.

An interesting occurrence of gem quality quartz was discovered in recent years by L. J. Lawrence, to whom I am indebted for the following information.

J

While crystallized quartz is generally not present in the Yerranderie lodes there were one or two places where small outcrops were prospected in the hope of finding sulphide ores. In one of these an early generation of imperfect quartz crystals has apparently grown in vughs in the lode material. Deposited on the ends of many of these imperfect crystals are a second generation of doubly terminated quartz crystals of perfect transparency and flawlessness. These can be collected loose in the dump of waste material from the excavation of the lode. Special attention is drawn to two fine crystals (D:38344–5) and a stone (D:38576) cut from another crystal.

Brown and Yellow Quartz. The principal varieties are citrine (light golden yellow) and cairngorm (deep brownish yellow) both perfectly transparent. Gradations of colour between these two extremes are also seen. Smoky quartz shows all these colours but in addition lacks perfect transparency mostly in only a very slight degree. The faint misty appearance is well known and can

Text-fig. 3.—X near the Lachlan River is the Mount MacDonald diamond locality.

best be described as smoky. It is often difficult to decide by inspection before cutting whether the stone will be perfectly transparent or smoky. A waterworn pebble of pale brown smoky appearance from Kookabookara collected by A. E. Gardner furnished a fine perfectly clear citrine of 20 carats when cut.

Much of what is called smoky quartz from the New England district is really perfectly transparent brown quartz, with little yellow in it. It grades from light to dark, and it is incorrect to call it either citrine or cairngorm. O. le M. Knight has cut a fine 100 carat stone of pale brown quartz from a waterworn pebble which showed exactly the same colour before cutting. A number of coloured varieties are found at Oban including dark brown (D:13391), light brown with a suggestion of violet (D:30014) and pale yellow (D:13047–9). Medium brown crystals were found at Hart's Mine, Torrington (D:27107). Many fine groups of clear pale brown quartz, often associated with molybdenite came from Kingsgate. In two such groups (D:30276, D:31231) the crystals are quite large some measuring 6in. by 3in. A medium brown material, with a mere suggestion of violet, as in the material from Oban, comes from Maurer's mine, near Kingsgate and from Tingha. Light brown specimens also came from Tingha. Two notable cut specimens are light brown quartz (D:15682) weighing 147 carats from Oban and a striking deep golden brown cairngorm (D:20995) weighing 13 carats from Giant's Den near Bendemeer. In most of these localities waterworn pebbles as well as crystals are found. Liversidge (1888)

has remarked that large crystals of smoky quartz are common almost throughout New England.

It should be noted that heat treatment of certain types of smoky and brown coloured quartz will produce citrine, but it is not known if this process has been applied to New South Wales varieties.

Amethyst. Notable occurrences are at Glen Elgin and Oban in the New England district. A fine cut stone (D:15684, weight 39 carats) comes from the latter locality. Curran (1896) mentions good specimens which provided fine cut stones from between Oberon and O'Connell's Plains. In latter years W. Nicholls, of Rylstone, collected amethyst from this same district, on Sidmouth Valley Creek, near Newstead, Tarana.
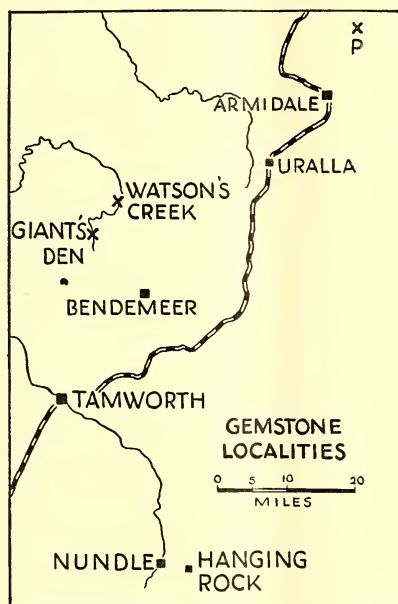
Text-fig. 4.—Gemstone localities in the southern part of New England. Giant's Den, an ill-defined locality, is regarded as part of the Watson's Creek tin field. Nundle is on the Peel River. The stream flowing north and north-west from Uralla is Rocky River. P.X is Puddledock.

Quartz with inclusions. Many attractive cabachons of rutilated quartz from Tingha are known. Smith (1926) has given a full list of the localities from which quartz containing inclusions of various minerals have been recorded. Most of these are represented in the Australian Museum collection. Special mention might be made of columnar crystals of black tourmaline included in medium brown quartz (D:27107) from Hart's Mine, Torrington, and the examples of molybdenite, bismuth, bismuthinite and arsenopyrite in quartz from Kingsgate.

TURQUOIS.

The only occurrence of this gemstone in the state is fully described by Curran (1896) from a locality near Bodalla on the South Coast. Ida Browne (personal communication) informs me that the turquois occurs in black cherts in the Wagonga series, tentatively regarded as Cambrian. She has given

further details of the location of the mineral in the Bodalla district. Two localities are mentioned, both in Ph. Wagonga, Co. Dampier. The first is $\frac{3}{4}$ mile south 20° east of Wagonga Trig. Station. The other is $\frac{1}{4}$ mile north of Mummuga Creek, Por. 171, north of Por. 28, about one mile upstream from the Prince's Highway crossing of the creek.

Two small polished stones (D:10114) show it to be an excellent blue colour, devoid of any green tint and somewhat paler than the best Persian material.

<div style="text-align:center">TITANITE</div>

Some years ago H. Hore of Broken Hill sent some yellowish green crystal fragments to H. F. Whitworth, of the Mining Museum, who identified the mineral as titanite. The writer has spent a few hours at the locality twice in recent years. The mineral occurs in an amphibolite mass on Huonville Station, some 11 miles south-east of Broken Hill. This amphibolite mass is shown on the Zinc Corporation geological map of the Broken Hill district (King and Thomson, 1953), the grid reference being 30,000 E : 46,000 S. Under the microscope the rock is seen to consist mainly of green to bluish-green hornblende. What small amount of plagioclase feldspar is present, is extensively altered to platy penninite and zoisite. A certain amount of prospecting has been done by numerous individuals, and all evidence of the original outcrop has been removed and a shallow excavation no more than 6 feet in depth and some 20 feet in diameter now exists. Some further digging in the excavation revealed a mass of unknown dimensions and shape that has intruded the amphibolite. For purposes of description it can be regarded as a pipe like mass. It is a mineral assemblage porous in nature, consisting principally of interlocking, slender, fresh, twinned albite crystals averaging 2mm. in length, transparent slender crystals of dark green epidote averaging 3mm. in length, magnetite and a large amount of yellowish green, pleochroic, fibrous, actinolite which has imparted a green colour to the assemblage. The actinolite has almost completely replaced a pronouncedly bluish-green hornblende. Remnants of this are scattered throughout the fibrous aggregates of actinolite. Microscopic examination shows small crystals of titanite also present. A good deal of this material has been excavated previously, and lies on dumps, and in this most of the actinolite has been removed by weathering. In the weathered mass the albite and epidote crystals are more easily visible. Associated with the albite-epidote-titanite assemblage are untwinned tabular crystals of albite ranging in length from 5mm. to 1·2cm. Crystals of 7mm. are quite common. These occur as compact masses in veins or as interlocking crystals apparently lining very shallow cavities. Calcite is associated with the albite in various ways. The most striking occurrence of calcite is in the form of large dark green cleavage masses found only on the dumps. The colour is imparted by an abundance of slender hair-like crystals of actinolite included in the calcite. Isolated crystals of the untwinned albite, of the same dimensions as above mentioned occur completely enclosed by the green calcite. These are often completely hollow only a thin outer shell remaining and in the cavities are deposited columnar crystals of epidote, and slender fibrous crystals of very pale yellowish actinolite. Platy masses of ilmenite intergrown with magnetite are occasionally found encrusting the calcite cleavage faces.

Associated with the albite-epidote assemblage are compact pale greenish-grey masses of very small calcite crystals with clayey material. Fibrous actinolite identical with that in the albite-epidote-titanite assemblage and lamellar chlorite masses are abundantly scattered throughout the matrix. The large untwinned albite crystals are also embedded in it. Actually large fragments of titanite were not seen in this matrix from the central pipe but were seen in whitish to yellowish earthy weathered fragments of it on the dumps.

One crystal of albite was noted with a small fragment of titanite attached. The titanite occurs in crystal fragments usually 4–8 mm. long but fragments 2·5cm. are sometimes seen. It frequently has a tabular habit and is sometimes sandwiched in between platy masses of ilmenite intergrown with a little magnetite. The titanite is also recovered as loose fragments in the dumps and in the soil in the immediate vicinity of the excavation.

From its occurrence in the pipe it seems as though the calcareous clayey material may be deuteric in origin having infiltrated cavities in the porous albite-epidote-titanite assemblage. Small remnants of the latter are frequently embedded in it. On the other hand there is evidence of some of the calcareous material having been re-deposited at a much later period as a secondary travertine or kunkar by solution of the primary calcite by circulating groundwater. In one specimen it exhibited a compact nodular structure, undoubtedly secondary in nature. Near the surface in the sides of the excavation seams of earthy travertine have been deposited along joint planes in the amphibolite.

If, as seems likely, the calcareous clayey matrix is deuteric in origin and bearing in mind that the whole primary assemblage is not massive but porous in nature, it is conceivable that crystals of titanite, epidote, actinolite and albite loosely attached in their original matrix could have been removed by deuteric solutions and embedded as deposition took place. On the other hand if some of the calcareous matrix is secondary it is conceivable that near the surface of the outcrop, titanite, albite, epidote and actinolite could have been in a detached state due to weathering and could have been embedded in the travertine as it was deposited from solution,

The titanite is scarce and mostly translucent and flawed. An occasional fragment transparent enough to yield a gemstone is found. O. le M. Knight has been able to obtain three cut stones from fragments obtained after several hours of collecting. The largest is a yellowish green stone, 1 carat in weight, showing the characteristic pronounced fire due to its high dispersion.

Prehnite.

Although prehnite comes into the category of an ornamental stone rather than a precious or semi-precious stone, it is of considerable interest on account of the abundant occurrence of material suitable for cutting at Prospect, close to Sydney.

The Prospect intrusion is a multiple sill and much of its nature and its wealth of minerals has been revealed by extensive quarrying. After the intrusion of a basic magma which cooled quickly in contact with the overlying Wianamatta shales to form a fine grained olivine analcite basaltic phase, there occurred a further intrusion of a body of magma which cooled more slowly and separated into two phases due to gravitative differentiation. These two phases consolidated to form olivine analcite dolerite one being more olivine rich and basic than the other and possessing picritic affinities. This latter is a porous rock. In both of these phases a wealth of secondary minerals principally calcite, hydrated silicates and zeolites has been deposited from deuteric solutions. Most notable of all these is prehnite, Prospect being one of the world's most famous localities for this mineral. It occurs most frequently in botryoidal masses. These are often deposited in vughs and crevices in both of the two dolerite types. In one instance the picritic phase is seen to have suffered the most severe attack by the deuteric solutions. Most attractive rich green curved crystal aggregates of prehnite grading into true botryoidal structure, have almost completely replaced the dolerite, little being left of the matrix other than masses of earthy chlorite, occasional fragments of pyroxene and slender needles of apatite. In addition to varying shades of green, pale fawn, lemon yellow,

rich golden brown, grey and almost colourless prehnite is found. It is mostly translucent, transparent material seldom being seen. Some two years ago A. Billett, lapidary at the Australian Museum, found that most attractive cabochons could be cut from all these types. Although the hardness of prehnite is only 6 to 6·5 somewhat below that required for good durability, it takes an excellent polish. Despite the fact that it is very cracked and flawed it shows a remarkable toughness and shows no tendency to fracture during the grinding and polishing process.

<div align="center">CONCLUSION.</div>

In conclusion let it be repeated that, especially at the present time, the economic significance of New South Wales gemstones is negligible. Even at its period of greatest activity, at about the turn of the century it was never of great significance.

The following figures taken from Belshaw and Jackson (1950) indicate the position. The official record of Australian diamond production is 208,001 carats valued at £156,031, of which 205,543 carats valued at £147,949 came from New South Wales. By far the largest portion of this came from Copeton. It is recorded that the Bingara output amounted to only £24,000. Belshaw and Jackson have advanced reasons as to why these figures may be underestimated by as much as 100%, but even then diamond mining could not be regarded as an industry of marked economic significance. Although opal mining is by far Australia's most important gemstone industry it is relatively insignificant, forming lesss than 0·05% of Australia's total mineral production. The value of New South Wales production is £1,600,000, more than half the total Australian production of £2,200,000. In recent years New South Wales production has been almost negligible. Australian production now comes mainly from South Australian fields. The total recorded value of New South Wales sapphire produced between 1919 and 1936 is £35,800, all from New England. By far the greatest number came from Sapphire. The total value of emeralds produced was only some £10,000.

It should be noted that excepting opal the great bulk of New South Wales gemstones has been associated with alluvial cassiterite in New England and won in the process of tin mining. Undoubtedly part of the reason for the relative scarcity in other areas of the state is because there alluvial tin mining is on a much smaller scale. Although diamonds associated with alluvial gold were and still are being won from deep leads adjacent to the present day Macquarie-Cudgegong-Turon River systems, they never seem to have been recorded from other important alluvial gold fields elsewhere in the state.

However, the many interesting scientific aspects of New South Wales gemstones make them a worthy subject of study. Gemstones are particularly pure varieties of minerals and hence lend themselves to chemical studies. They very often show great perfection of crystalline form and hence have always been sought after for crystallographic studies. Since one of the necessary properties of a gemstone is perfect transparency either in the rough or cut form they form ideal subjects for optical studies.

Throughout the last twenty years a separate science known as gemmology has emerged as a branch of mineralogy. The stimulus has come as much from scientifically minded members of the jewellery trade as from mineralogists. One interesting field that is now almost solely the province of the gemmologist is the study of minute inclusions of other minerals, liquids and gases that frequently are found in minerals. A transparent cut stone lends itself admirably to microscopic examination of such features.

As might be expected gemmology is in a very advanced stage in Great Britian, America and certain European countries. The study of gemmology in Australia received a great impetus some nine years ago when the Gemmological Association of Australia was founded, which now has amongst its membership many enthusiastic and competent gemmologists. It is felt that we are on the threshold of a new era in gemmology when the refined and accurate techniques of other countries will be applied to the study of our native gemstones.

In the preparation of this lecture numerous gemmologists have given generous assistance. Arthur Wirth has done a good deal of experimenting in recent months with Clerici's solution used as a heavy liquid for the determination of specific gravities. He made these solutions available, which proved invaluable in accurately determining small fragments of gem minerals. O. le M. Knight (1951) some years ago designed and constructed a most accurate balance of unusual design for the rapid determination of specific gravities and was good enough to place it at my disposal. Use was made of specimens from the collections of both these gentlemen.

Bearing in mind the object of the Royal Society of New South Wales which includes " studies and investigations in Science and especially on such subjects as tend to develop the resources of Australia and to illustrate its Natural History and Productions ", it seems that a survey of the gemstones of New South Wales has been an appropriate subject to place before you in honouring the memory of the Rev. W. B. Clarke. One might end suitably by quoting the words of a past President of the Royal Society, Professor Smith who in 1871 commented on the change of title of this society from Philosophical Society to Royal Society in the following words—" A strictly Philosophical Society might be expected to confine its attentions to matters of speculation and pure science, while in our circumstances it is expedient to devote our energies more to applied science and matters of obvious practical utility not however refusing to entertain questions of speculative philosophy when competent members bring them under our notice. Following the example of the Royal Society of England we can embrace the whole range of human knowledge and skill, avoiding only such topics as usually end in angry controversy."

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HANKEL TRANSFORMS OF FUNCTIONS ZERO OUTSIDE A FINITE INTERVAL.

By JAMES L. GRIFFITH.

School of Mathematics, New South Wales University of Technology.

SUMMARY.

If we define the Hankel transform $G(u)$ of a function $g(x)$ by

$$G(u) = \text{l.i.m.} \int_0^\infty x J_\nu(ux) g(x) dx, \quad \nu > -\tfrac{1}{2}$$

it is proved that

(α) $g(x)$ is zero for almost all $x > A$, and
(β) $x^{\frac{1}{2}} g(x)$ belongs to $L^2(0, A)$,

when and only when

(i) $G(z)$ is analytic in z for $0 \leqq \arg z \leqq \pi$, $|z| > \varepsilon > 0$,
(ii) $z^{\frac{1}{2}} G(z) = \mathrm{O}(e^{A \operatorname{Im} z})$ as $|z| \to \infty$, $\operatorname{Im} z \geqq 0$,
(iii) $G(u e^{i\pi}) = e^{i\pi\nu} G(u)$, $u > 0$,
(iv) $u^{\frac{1}{2}} G(u)$ belongs to $L^2(0, \infty)$, and
(v) $|G(z)| = \mathrm{O}(|z|^\nu)$ as $z \to 0$.

I. INTRODUCTION.

When using transform methods, it is most important to have at one's disposal theorems which allow the determination of non-trivial properties of the original functions from those of the image function.

In [P.W.] (theorem X, p. 13), Paley and Wiener proved the well-known theorem : If $F(\xi)$ is the Fourier transform of $f(x)$, then $f(x)$ is zero almost everywhere for $|x| > A$, and belongs to $L^2(-A, A)$, when and only when $F(z)$ is an integral function satisfying

$$F(z) = \mathrm{o}(e^{A|z|}) \quad \dots\dots\dots\dots\dots\dots\dots (1.1)$$

with $F(\xi)$ belonging to $L^2(-\infty, \infty)$.

When we say that "$f(x)$ belongs to $L^p(a, b)$" we mean that $f(x)$ is measurable in the Lebesgue sense over (a, b) and

$$\int_a^b |f(x)|^p dx$$

exists in the Lebesgue sense.

The aim of this paper is to prove the theorem quoted in the Summary, which is the analogue in the Hankel transform theory of Paley and Wiener's theorem.

Recalling that $J_\nu(t)$ is the Bessel function of the first kind of order ν, defined by

$$J_\nu(t) = \sum_{m=0}^{\infty} \frac{(-1)^m(\tfrac{1}{2}t)^{\nu+2m}}{m!\,\Gamma(\nu+m+1)}, \quad \dots\dots\dots\dots (1.2)$$

the form of the Hankel transform theorem which will be used will be the following :

Assuming that

$$\nu > -\tfrac{1}{2} \quad \dots\dots\dots\dots\dots\dots (1.3)$$

and that $x^{\frac{1}{2}}g(x)$ belongs to $L^2(0, \infty)$ then there exists a $G(u)$ such that $u^{\frac{1}{2}}G(u)$ belongs to $L^2(0, \infty)$ and that

$$T[g(x)] \equiv G(u) = \int_0^\infty xJ_\nu(ux)g(x)dx \quad \dots\dots\dots\dots (1.4)$$

and

$$T^{-1}[G(u)] \equiv g(x) = \int_0^\infty uJ_\nu(xu)G(u)du \quad \dots\dots\dots\dots (1.5)$$

where both the integrals in equations (1.4) and (1.5) are to be taken in the sense of the limit in the mean square.

By saying that the equation (1.4) exists as a limit in the mean square, we understand that

$$\lim_{A\to\infty} \int_0^\infty \Big| G(u) - \int_0^A xJ_\nu(ux)g(x)dx \Big|^2 du = 0$$

This form of the transform theorem is that used in [T.F.I.], chapter VIII, and [B.C.], chapter V.

In order to save repetition, we will consider functions as identical if they are equal almost everywhere. In particular, if we say that a function is zero for $x > A$, we mean that it is equal almost everywhere to a function which is zero for $x > A$.

In sections 3 and 4, the following Parseval theorems will be needed :

O_1 :   If $x^{\frac{1}{2}}f(x)$ and $x^{\frac{1}{2}}g(x)$ both belong to $L^2(0, \infty)$ and

$$T[f(x)] \equiv F(u)$$

and

$$T[g(x)] \equiv G(u)$$

then

$$\int_0^\infty xf(x)g(x)dx = \int_0^\infty uF(u)G(u)du, \quad \dots\dots (1.6)$$

the integrals holding in the L^1-sense.   This is Theorem 1 of [P.M.O.] with a notation change.

O_2 :   If $u^{\frac{1}{2}}G(u)$ belongs to $L^1(0, \infty)$ and $u^{\frac{1}{2}}F(u)$ belongs to $L^1(0, c)$ and $u^{-1\frac{1}{2}}F(u)$ belongs to $L^1(c, \infty)$ where $c > 0$, then equation (1.6) holds.   This is Theorem 4 of [P.M.O.].

2. The Necessary Conditions.

We assume now that (α) and (β) hold.

It is immediately obvious from (β) that $x^{\frac{1}{2}}g(x)$ belongs to $L^1(0, A)$.

In this section we write $z=u+i\beta$ and restrict our discussion to the half plane $\beta \geq 0$.

Referring to equation (1.4), we have now

$$z^{\frac{1}{2}}G(z)=\int_0^A (zx)^{\frac{1}{2}}J_\nu(zx)[x^{\frac{1}{2}}g(x)]dx \quad \dots\dots\dots \quad (2.1)$$

The only singularities of $J_\nu(t)$ and $J_\nu'(t)$ are at the origin and from [W.B.F.], p. 49, we derive

$$| (xz)^{\frac{1}{2}}J_\nu(xz) | \leq \frac{x^{\nu+\frac{1}{2}}|z|^{\nu+\frac{1}{2}}e^{\beta x}}{2^\nu\Gamma(\nu+1)} \quad \dots\dots\dots\dots \quad (2.2)$$

and

$$\left|\frac{\partial}{\partial z}\{(xz)^{\frac{1}{2}}J_\nu(xz)\}\right| \leq \left[\frac{1+2|\nu|}{\Gamma(\nu+1)}+\frac{x^2|z|^2}{\Gamma(\nu+2)}\right]2^{-\nu-1}x^{\nu+\frac{1}{2}}|z|^{\nu-\frac{1}{2}}e^{\beta x} \quad \dots \quad (2.3)$$

Thus (i) follows immediately.

Now we have

$$G(z)=\int_0^\infty xJ_\nu(zx)g(x)dx$$

and using again the inequality (2.2), obtain

$$|G(z)| \leq \frac{|z|^\nu e^{A\beta}}{2^\nu\Gamma(\nu+1)}\int_0^A x^{\nu+1}|g(x)|\,dx$$

Since $\nu > -\frac{1}{2}$ and $x^{\frac{1}{2}}g(x)$ belongs to $L^1(0, A)$, the integral on the right exists and

$$G(z)=O(|z|^\nu)$$

as $|z|\to 0$. This is (v).

To obtain further information concerning the behaviour of $G(z)$ when $|z|$ is large, we write

$$G(z)=\left[\int_0^\eta +\int_\eta^A \right]xJ_\nu(zx)g(x)dx$$

$$=I_1+I_2 \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (2.4)$$

with $0<\eta<A$.

Inequality (2.2.) gives

$$|I_1| \leq \frac{2^{-\nu}}{\Gamma(\nu+1)}|z|^\nu e^{\eta\beta}\int_0^\eta x^{\nu+1}|g(x)|\,dx$$

$$\leq \frac{2^{-\nu}}{\Gamma(\nu+1)}|z|^\nu e^{\eta\beta}\int_0^A x^{\nu+1}|g(x)|\,dx$$

$$=O(|z|^\nu e^{\eta\beta}),\ \eta<A \quad \dots\dots\dots\dots\dots \quad (2.5)$$

as $|z|\to\infty$.

In I_2, we observe that $x \neq 0$, then the asymptotic formula for the Bessel function [W.B.F.], p. 199, gives

$$| (zx)^{\frac{1}{2}} J_\nu(zx) | < C e^{\beta x}$$

for sufficiently large $| zx |$, where C is a constant independent of z and x. Thus

$$| I_2 | \leq E | z |^{-\frac{1}{2}} e^{A\beta} \int_\eta^A x^{\frac{1}{2}} | g(x) | \, dx$$

for some finite constant E, provided that $| z |$ is sufficiently large. That is

$$| I_2 | \leq E | z |^{-\frac{1}{2}} e^{A\beta} \int_0^A x^{\frac{1}{2}} | g(x) | \, dx$$

$$= O(| z |^{-\frac{1}{2}} e^{A\beta}) \quad \dots\dots\dots\dots\dots\dots (2.6)$$

as $| z | \to \infty$.

If now $\beta > 0$, we combine equations (2.5) and (2.6) and obtain

$$| z^{\frac{1}{2}} G(z) | = O(e^{A\beta}) \quad \dots\dots\dots\dots\dots\dots (2.7)$$

as $| z | \to \infty$.

When $\beta = 0$, $(zx)^{\frac{1}{2}} J_\nu(zx)$ is bounded ($< M$, say). Then

$$| z^{\frac{1}{2}} G(z) | < M \int_0^A x^{\frac{1}{2}} | g(x) | \, dx$$

$$= O(1) \quad \dots\dots\dots\dots\dots\dots\dots\dots (2.8)$$

as $| z | \to \infty$.

Equations (2.7) and (2.8) give (ii).

If, in equation (1.2), we replace t by zx, we easily find

$$G(z) = z^\nu \int_0^A x^{1+\nu} P(x, z) g(x) dx$$

where $P(x, z)$ is analytic and even in both z and x. Conclusion (iii) of the summary follows immediately.

We finally observe that (iv) follows from the fundamental theorem quoted in the introduction.

3. THE SUFFICIENT CONDITIONS.

In this section we will show that the necessary conditions are also sufficient. We shall show that if $G(z)$ satisfied (i)-(v), then

$$T[g(x) E(a-x)] = T[g(x)], \quad a > A, \quad \dots\dots\dots\dots (3.1)$$

where

$$E(s) = \begin{cases} 1, & s > 0. \\ 0, & s < 0. \end{cases}$$

The inversion theorem will give the result.

Using equation (8) of [W.B.F.], p. 134, and recalling that $\nu > -\frac{1}{2}$, we obtain

$$\int_0^a x J_\nu(ux) J_\nu(tx) dx = \frac{a}{u^2 - t^2} \{ u J_{\nu+1}(ua) J_\nu(ta) - t J_\nu(ua) J_{\nu+1}(ta) \}$$

$$= w(a, t, u), \text{ (say).} \quad \dots\dots\dots\dots\dots\dots (3.2)$$

That is

$$T[J_\nu(tx)E(a-x)]=w(a, t, \dot{u}) \quad \ldots\ldots\ldots\ldots (3.3)$$

It is clear that $J_\nu(tx)E(a-x)$ belongs to both $L^2(0, \infty)$ and $L^1(0, \infty)$. We now suppose that $u^{\frac{1}{2}}G(u)$ and (*a fortiori*) that $x^{\frac{1}{2}}g(x)$ belong to $L^2(0, \infty)$. The Parseval Theorem O_1 gives

$$\int_0^\infty vw(a, u, v)G(v)dv=\int_0^\infty x[J_\nu(ux)E(a-x)]g(x)dx$$

$$=\int_0^\infty xJ_\nu(ux)[g(x)E(a-x)]dx ;$$

that is

$$T[g(x)E(a-x)]=\int_0^\infty tw(a, u, t)G(t)dt. \quad \ldots\ldots\ldots\ldots (3.4)$$

We now examine

$$\int_0^\infty tw(a, u, t)G(t)dt \quad \ldots\ldots\ldots\ldots (3.5)$$

where as mentioned above $G(z)$ possesses the properties (i)-(v). It will be convenient in this section to write $z=t+i\beta$.

The method we will use will follow closely that of [W.B.F.], p. 423 *et seq.* Consider

$$\int_c \frac{zG(z)}{z^2-u^2}\{zH^{(1)}_{\nu+1}(za)J_\nu(ua)-u H^{(1)}_\nu(za)J_{\nu+1}(ua)\}dz\ldots\ldots\ldots (3.6)$$

where

$$H^{(1)}_\nu(z)\equiv J_\nu(z)+iY_\nu(z)$$

is the Bessel Function of the third kind [W.B.F.], p. 73, and the contour consists of a semi-circle (radius R) above the real axis, and the real axis between $-R$ and $+R$, with small indentations (radius ε) at $-u$, $+u$ and O.

Since the integrand is analytic inside the contour, the integral vanishes. Using (iii) and (v), and

$$H^{(1)}_\nu(te^{i\pi})=e^{-\nu\pi i}H^{(1)}_\nu(t)-2e^{-\nu\pi i}J_\nu(t)$$

([W.B.F.], p. 75, equation 5) we obtain for the contribution from the real axis (after the limits $\varepsilon\to 0$ and $R\to\infty$ have been taken)

$$\int_0^\infty \frac{tG(t)}{t^2-u^2}\{2tJ_\nu(ua)J_{\nu+1}(ta)-2uJ_{\nu+1}(ua)J_\nu(ta)\}dt \quad \ldots\ldots (3.7)$$

The indentation at $-u$ gives

$$(-\tfrac{1}{2}\pi i)G(u)\{uJ_\nu(ua)[H^{(1)}_{\nu+1}(ua)-2J_{\nu+1}(ua)]$$

$$-uJ_{\nu+1}(ua)[H^{(1)}_\nu(ua)-2J_\nu(ua)]\} \quad \ldots\ldots\ldots (3.8)$$

The indentation at $+u$ gives

$$(-\tfrac{1}{2}\pi i)G(u)\{uJ_\nu(ua)H^{(1)}_{\nu+1}(ua)-uJ_{\nu+1}(ua)H^{(1)}_\nu(ua)\} \quad \ldots\ldots \text{(3.9)}$$

There is no contribution from the indentation at the origin.

To determine the contribution from the large semi-circle, we need a rather obvious lemma.

Lemma.

If S is the semi-circle with centre the origin, and radius R and

$$|G(z)|=O(|z|^{-\eta}e^{-b\beta}) \text{ where } \eta>0, \ b>0$$

then

$$\lim_{R\to\infty} \int_S G(z)dz=0$$

Proof.—When R is sufficiently large,

$$\left|\int_S G(z)dz\right| < K\int_0^\pi e^{-bR\sin\theta}R^{1-\eta}d\theta \text{ for some } K>0$$

$$<2K\int_0^{\frac{1}{2}\pi} e^{-2R\theta/\pi}R^{1-\eta}d\theta$$

$$=K\pi R^{-\eta}[1-e^{-R}]$$

$$\to 0, \text{ as } R\to\infty.$$

From [W.B.F.], p. 201, we have

$$H^{(1)}_\nu(z)\sim Mz^{-\frac{1}{2}}e^{iz} \text{ as } |z|\to\infty \quad \ldots\ldots\ldots\ldots \text{(3.10)}$$

(for constant M).

Assumption (ii), equation (3.10) and the Lemma show that the contribution from the large semi-circle vanishes (in the limit) when $a>A$, which we now assume.

Combining our results, we obtain

$$\int_0^\infty tw(a,u,t)b(t)dt$$

$$=(-\tfrac{1}{2}\pi i)auG(u)\{J_{\nu+1}(ua)H^{(1)}_\nu(ua)-J_\nu(ua)H^{(1)}_{\nu+1}(ua)\}$$

$$=\tfrac{1}{2}\pi auG(u)\{J_{\nu+1}(ua)Y_\nu(ua)-J_\nu(ua)Y_{\nu+1}(ua)\}$$

$$=G(u)$$

by Lommel's formula ([W.B.F.], p. 77).

Referring back to equation (3.4), we see that we have proved equation (3.1).

To complete this section we have only to remark that the inversion theorem shows that $x^{\frac{1}{2}}g(x)$ belongs to $L^2(0,A)$.

4. THE L^1-CASE.

It is obvious that if $x^{\frac{1}{2}}g(x)$ belongs to $L^1(0,A)$, the whole of section 2 is valid except the last paragraph. We cannot say that $u^{\frac{1}{2}}G(u)$ belongs to any particular L-class.

In section 3, if we replace (iv) by " $u^{\frac{1}{2}}G(u)$ belongs to $L^1(0, \infty)$ " we may derive equation (3.4) by using theorem O_2 of the Introduction. The whole of section 3 now follows up to the point at which we proved $T[g(x)] = T[g(x)E(a-x)]$. To obtain (α) we must use the inversion theorem in the form of [T.F.I.], theorem 135. An examination of the proof of [T.F.I.], theorem 135, indicates that since $g(x) = 0$ for $x > A$, $x^{\frac{1}{2}}g(x)$ will belong to $L^1(0, A)$.

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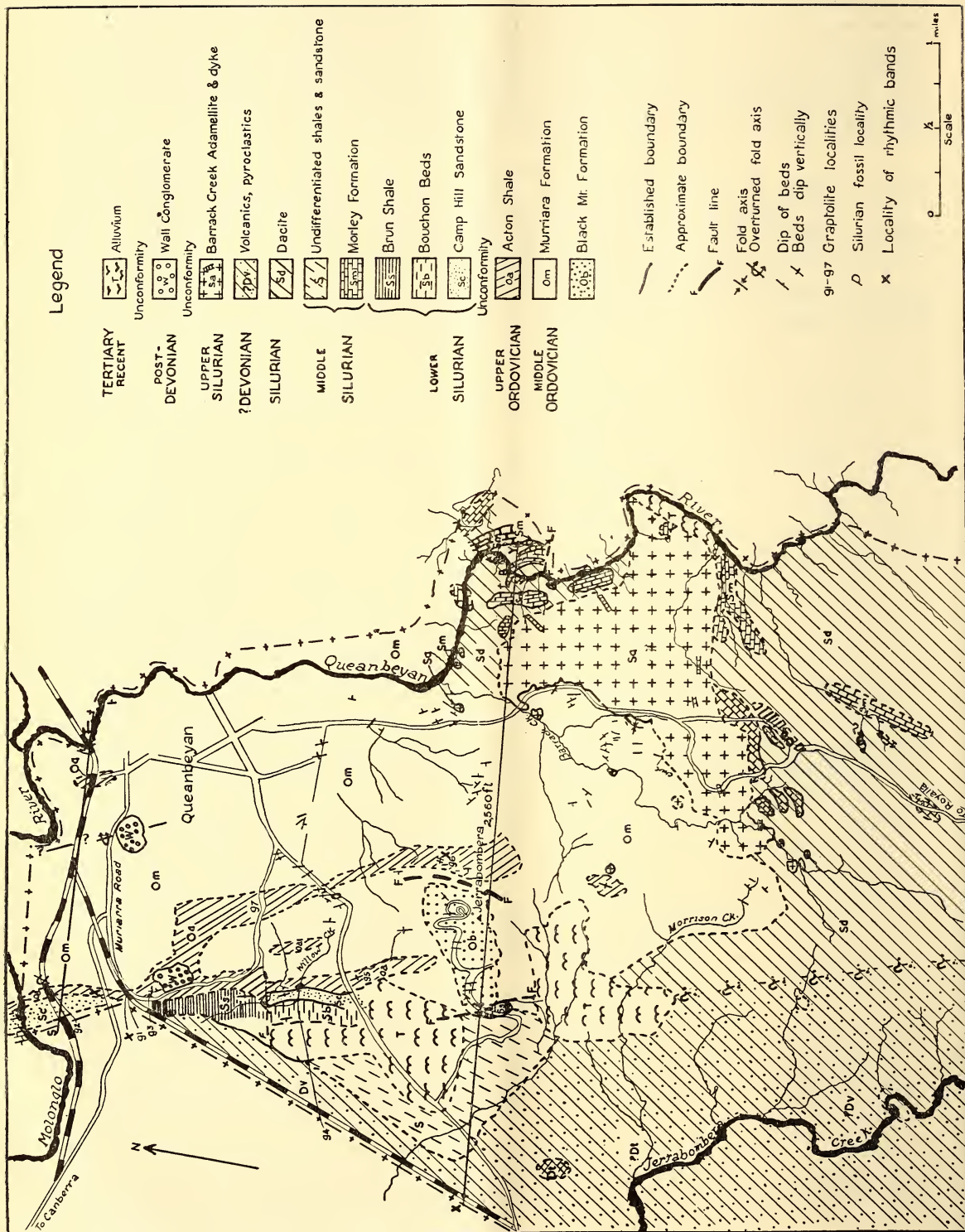
GEOLOGY OF THE QUEANBEYAN DISTRICT.

By June R. P. Phillips.

(With Plate III and two Text-figures.)

INTRODUCTION.

The Queanbeyan district, situated on the Southern Tablelands of N.S.W., is two hundred miles south by rail from Sydney and seven miles east by road from Canberra. The district described comprises the Parish of Queanbeyan, and the northern part of the Parish of Googong.

The first geological report of the area appears in Mahony and Taylor's " Geological Reconnaissance of the Federal Capital Territory " (1913). The exposed sandstone, shale and silicified limestone were considered to belong to the Silurian system. Carne and Jones (1919) make brief mention of the Queanbeyan limestone resources. Harper (1927) gives a brief report on the slate cropping out in Portion 42, 44, Parish of Queanbeyan. In 1929, Keble and
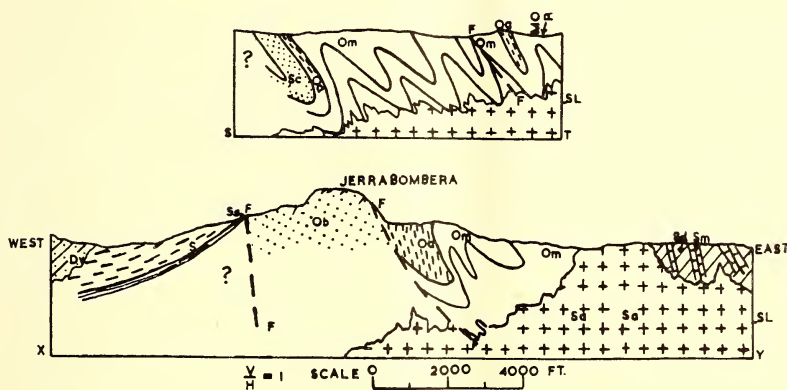
Text-fig. 2.

Harris published " A Collection of Graptolites from the Federal Capital Territory ", describing six forms equivalent in Britain with the *Dicranograptus clingani* Zone. The title is misleading, as the collection locality is stated to be four miles south of Queanbeyan (in the State of N.S.W.). The actual collection was made from the slate being exploited for roofing at the eastern foot of Mount Jerrabombera, Portion 42, 44, Parish of Queanbeyan. This locality has been selected by Sherrard (1953) as the type locality in N.S.W. of the Zone of *Orthograptus quadrimucronatus* and *Pleurograptus linearis*.

McInnes (1949) indicated a regional distribution of Ordovician and Silurian. Öpik (1954) in his detailed investigation of the Canberra region has extended his observations into the Queanbeyan region.

Stratigraphy.

At least 2,000 ft. of Ordovician sediments and 900 ft. of Silurian sediments form the general succession in the Queanbeyan region, and the succession as listed in Table 1 is arranged in descending order.

Table 1.

AGE	QUEANBEYAN SEQUENCE	COLUMNAR SECTION	
TERTIARY–RECENT	ALLUVIAL DEPOSITS		
POST DEVONIAN	•WALL CONGLOMERATE		
? DEVONIAN	VOLCANICS, PYROCLASTICS		
UPPER SILURIAN	BARRACK CREEK ADAMELLITE		
SILURIAN	DACITES		
MIDDLE SILURIAN	MORLEY FORMATION		DACITE
LOWER SILURIAN	BRUN SHALE		
	BOUCHON BEDS CAMP HILL SANDSTONE		
UPPER ORDOVICIAN	ACTON SHALE		
MIDDLE ORDOVICIAN	MURIARRA FORMATION		RADIOLARITE
OLDER THAN MIDDLE ORDOVICIAN	BLACK MOUNTAIN FORMATION		

SCALE : 0   500 FT.

• Thickness of unit not to scale

1. Ordovician.

(1) *Black Mountain Formation.*

These rocks are the oldest in the Queanbeyan area and as they are litho-logically identical with the type area in the Canberra sequence, they are regarded as being older than Middle Ordovician. In the Queanbeyan area their outcrop is limited to the Jerrabombera inlier.

The easterly exposures are massive grey to white quartzite and occasionally, bands are peppered with abundant clay pellets (maximum diameter of 4 cm.).

Moving towards the western margin, the quartzite is succeeded by similar bands containing clay pellets, and further on, interstratified shale bands occur. Sub-angular quartz grains (maximum diameter 0·1 mm.) are poorly sorted and together with a small proportion of feldspar and tourmaline, are embedded in a micaceous matrix. The shadowy extinction, textural character and the development of chlorite indicate limited regional metamorphism.

Faulting on the eastern margin, which took place towards the end of Silurian times, has upthrown the Black Mountain Formation against Middle to Upper Ordovician sandstone and phyllite, with a displacement of possibly 900 ft. On the eastern side of Jerrabombera Mountain, strongly slickensided and crumpled phyllites indicate the zone of fracture.

Structural relations between the adjacent chocolate-coloured ? Silurian shale exposed on the west is not apparent. The incompetent shale is strongly cleaved, and since it is unfossiliferous it has been correlated on lithological grounds with the Brun Shale. If this correlation is correct a hiatus of at least 1,400 ft. exists.

(2) *Muriarra Formation.*

These beds form an alternating sequence of phyllite and sandstone, occupying a meridional belt through the central part of the area. The rhythmic succession of beds is exposed along the Muriarra Road, which runs east-west at the northern part of Queanbeyan, after which they have been named.

In the railway cutting west of Queanbeyan Station are exposed close folds overturned to the west with axes dipping 50° to the east (Fig. 2, 1). This tight folding of the sediments makes the estimated thickness of 960 ft. only an approximation.

The lower beds are thinly bedded, alternating weathered green phyllite and yellow to white sandstone. Greater development of shales occurs in the higher part of the succession, and near the top shales pass conformably into the Upper Ordovician Acton Shale. These Muriarra shales are frequently laminated and belong to the chlorite zone of regional metamorphism. Bands of strongly jointed radiolarite, 10 to 15 ft. thick, occur in the middle of the sequence. The sandstones, in part, are micaceous ; quartz grains show undulose extinction and possess a preferred orientation as a result of low grade metamorphism. Subgreywackes (Pettijohn definition, 1949) occur east of Queanbeyan Station in the lower part of the succession.

Lithologically the Muriarra Formation may be correlated with the lower Middle to lower Upper Ordovician Pittman Formation of Canberra.

(3) *Acton Shale.*

This formation consists of black shale and occurs mainly in two meridional belts striking north-north-west. The shale is well exposed in the north-west corner of the area, where the thickness is at least 100 ft. Isoclinal folding, strike and thrust faults are evident in these sections. At the Canberra Meatworks the shale is steeply dipping to the east, and overlies disconformably, steeply dipping Camp Hill Sandstone (Lower Silurian age), hence indicating overfolding of the sediments. A mile to the south, in Willow Creek, the Eastonian slates, steeply dipping to the west, are overlain unconformably by westerly dipping Lower Silurian sandstone, indicating a change to normal folding.

The upper part of the formation is blue-grey slate. On occasions, the slate is so fissile as to be papery. Silicification has hardened the slate in many places, and as a result laminated bedding is well preserved. Near the top of the formation current bedded, pale yellow sandstone occurs. Towards the lower part of the formation are striking rhythmic banded, soft shales (well exposed in

sites X on Text-figure 1). The lighter grey bands (average width 1·5 in.) are wider than the darker bands and lack carbonaceous material that is abundant in the darker bands. A similar type of ribbon banding has been described by S. J. Copland (1946) in the Ordovician sediments of the Shoalhaven River Gorge.

Graptolites are present in the upper horizons of the black shales in a number of localities, which are indicated in Text-figure 1 by g1 to g7. The graptolites are generally poorly preserved as white or red iron-stained films on the bleached slate. The forms identified include :

> *Dicellograptus morrisi* Hopkinson—common g6.
> *Dicellograptus* cf. *elegans* Carruthers—g6, g1.
> *Dicellograptus* cf. *forchammeri* Geinitz—g6.
> *Dicellograptus* cf. *pumilus* Lapworth—g6.
> *Diplograptus* (*Orthograptus*) *pageanus* Lapworth—g1, g6.
> *Climacograptus* cf. *tubiliferus* Lapworth—common g1.
> *Dicranograptus* cf. *furcatus* (Hall)—g1.
> *Dicranograptus* cf. *furcatus* (Hall) var. *exilis* Ruedemann—g1.
> *Dicranograptus nicholsoni* Hopkinson cf. *mut. geniculatus* Ruedemann and Decker—g1.
> *Glossograptus quadrimucronatus* (Hall)—g1, g2.
> *Diplograptus* (*Orthograptus*) *calcaratus* Lapworth—g3, g4, g5.

Of interest is the possible occurrence of Leptograptids at g1. Considering also the Queanbeyan genera listed by Sherrard (1954), the assemblages if referred to the British succession contain forms common to Zone 12 and Zone 13. These shales of the Queanbeyan area may be correlated with the Eastonian Acton Shale of the Canberra region.

2. Silurian.

(1) *Camp Hill Sandstone.*

Quartzose sandstone rests disconformably on Eastonian Acton Shale, and represents the first sediments to be deposited in the Silurian in the Queanbeyan district.

Exposures of the buff to white sandstone are seen in the western part of the area ; in Willow Creek they are steeply dipping to the west, in the Canberra-Queanbeyan railway cutting and along the Molonglo River the sediments are overfolded to the west.

Friable sandstone beds are interspersed throughout the 150 ft. of strata, and shaly bands appear in the upper horizons. The sandstone contains a fauna of brachiopods, trilobites, gastropods and corals, but it is difficult to obtain specimens sufficiently well preserved to identify. This sequence is an easterly extension of the Camp Hill Sandstone of the Canberra region which has been established by Öpik as Lower Silurian in age.

(2) *Bouchon Beds.*

The Bouchon Beds are dark grey to black mudstone with a small limestone lens. The mudstone contains poorly defined fossil casts. The only outcrop of the Bouchon Beds west of Willow Creek measures 20 ft. in width and strikes 170° with westerly dip. Unfortunately the junction with the underlying Camp Hill Sandstone, and with dacite on the western margin, is obscured.

(3) *Brun Shale.*

The Brun Shale is yellow brown mudstone with interbedded thin sandstone bands. Thickness, 300 ft. to 400 ft.

Northwards, 200 yards from the Camp Hill Sandstone in Willow Creek, the Brun Shale, striking 160° and with vertical dip, is faulted against the Lower Silurian Camp Hill Sandstone. The western margin of the outcrop appears to be unmetamorphosed by adjacent dacite.

The brachiopod *Fardenia* sp. is the only fossil so far found (location marked in Text-fig. 1).

In Portion 41, Parish of Queanbeyan, near the western loop of Mount Jerrabombera Road, very poorly exposed interbedded sandstone and shale occur. These may overlie the Brun Shale and are possibly Lower to Middle Silurian.

(4) *Morley Formation.*

This Formation (locally known as the Morley limestone) has a thickness of at least 500 ft. and consists of black phyllite, tuff, broad lenses of calcite-dolomite marble and sandstone. Severe shearing and crushing involving recrystallization and silicification, together with extensive dolomitization of certain lenses, have destroyed all organic forms except a few crinoid stems in the marble in Portion 98, Parish of Googong.

The Morley Formation is exposed in the south-east corner of the area, and the general structural trend of the formation curves around the Barrack Creek Intrusion, with steep easterly and south-easterly dips. Metamorphosed quartzose sandstone with a calcareous matrix overlies the phyllite and is recognized as the upper member of the Morley Formation.

In Portions ML5, 47, Parish of Queanbeyan, the marble lenses are extremely puckered as a result of shearing. Finely laminated, platy limestone is often interbedded with quartz sericite schist. In certain sections the marble shows strong banding due to segregation of the iron oxide.

The lithology of alternating shale and limestone, overlain by thin sandstone and associated with tuffs and dacite, is very similar to the Molonglo Sandstone and Molonglo Formation of Canberra, which are Middle Silurian (Öpik, 1954).

? Devonian.

Dacites, rhyolites and tuffs cover the south-western part of the area. Poor exposures and a great variability of rock types make mapping difficult. This western suite of rocks is more tuffaceous and more glass-rich than the easterly Googong dacite of Silurian age. These may be Devonian, with the exception of the dacite in the railway cutting near Letchworth in contact with Silurian sediments to the east. This may be an intrusive of Silurian age.

The fine-grained chocolate coloured tuff in Portion 38, Parish of Queanbeyan, consists of angular quartz grains of variable size (1 mm. in diameter), some feldspar, and chlorite set in a very fine grained matrix, strongly stained with iron oxide. Further south a more coarse-grained member occurs ; this weathers to a bluish colour. Large resorbed quartz crystals and feldspar crystals are set in a felsophyric groundmass, which has a definite flow structure and in many respects is reminiscent of a welded tuff. Calcite is frequently clustered at the side of the larger grains of quartz, or feldspar, and the larger flakes of chlorite material are shredded. Yet another rock type occurs in Jerrabombera Creek. This type shows evidence of stress and strain, and the trace of shear planes indicates it is associated with a zone of faulting. It consists of very angular fragments of quartz, and feldspar in a tuffaceous groundmass of diopside, mica, chlorite, quartz, andesine and albite.

3. Post–Devonian.

Wall Conglomerate.

Two well consolidated outliers of conglomerate, a quarter of a mile apart, are found in the north-westerly part of Portion 53, Parish of Queanbeyan. They occur at 2,030 ft. above sea-level, and are nearly 20 ft. thick, consisting of sub-angular pebbles of quartz, quartzite and chert. In addition to these, the western outcrop which overlies the Acton Shale contains black shale fragments, and the eastern one which overlies the Muriarra Formation contains sandstone fragments. The beds are stratified into fine and coarse layers which grade from boulder conglomerate (maximum diameter 15 cm.) down to grit, and numerous quartz veins cut through the outcrops, resulting in a strongly silicified mass. The hardened, silicified nature of the conglomerate seems to be the result of laterization as suggested by Hallsworth and Costin (1953).

The sub-angular nature of the particles, their chaotic arrangement and the localized rock types seem to indicate a local scree, rather than a far-travelled deposit. These strongly ferruginous outcrops are regarded as the indurated zone of a laterite profile.

Similar deposits occur throughout the State of N.S.W. and have generally been regarded as Tertiary deposits. Recently Öpik (1954) has regarded some deposits at Canberra as Permian fluvioglacials.

PETROLOGY.

Igneous and pyroclastic rocks outcropping over a large area are essentially acid in composition. The first intrusives of the region are sill injections of porphyritic dacite intruding the more easterly sediments and pyroclastics. The strong shearing and fracturing suffered by the dacites is most pronounced in the south-easterly region where a prominent cleavage strikes 225°, dip south-east, across the outcrops. In Portion 109, Parish of Googong, an isolated low ridge of dacite lacks the characteristic cleavage, although under the microscope the rock shows shear planes and other deformational features. This may be due to the fact that this dacite is not situated in the main zone of shearing.

To me the intrusive, sill-like form of some of the dacites may be seen in the south-western part of the area along Morrison's Creek in Portion 37, Parish of Googong, where dacite intrudes Middle Ordovician sediments ; and in the quarry cut into limestone in Portion ML5, Parish of Queanbeyan, where the dacite intrudes along the bedding of the limestone. However, Dr. W. R. Browne (personal communication) considers these outcrops to be tuffs.

The dacite consists of large resorbed quartz phenocrysts, with undulose extinction ; lath-shaped plagioclase (oligoclase-andesine), frequently sericitized and albitized ; a variable amount of orthoclase, and smaller phenocrysts of bleached or chloritized biotite. Hornblende is commonly altered to magnetite dust.

The groundmass consists of very fine-grained quartz, sericite and biotite. The biotite is weathered to limonite and forms dark, weaving streaks. The groundmass of these dacitic rocks varies considerably, a feature which Joplin (1943) described when discussing quartz-feldspar-porphyries from the Cooma district. In the more strongly sheared porphyritic rocks quartz crystals are stretched, with planes of movement cutting through the sections displacing twin lamellæ of the feldspar. The stresses acting on the dacites have been sufficient to crush both the groundmass and the phenocrysts.

Metamorphism Due to Dacite.

Contact metamorphism by the dacite has resulted in silicification of the sandstone and shale. The dacite isolates, in outcrop, the southernmost lens of
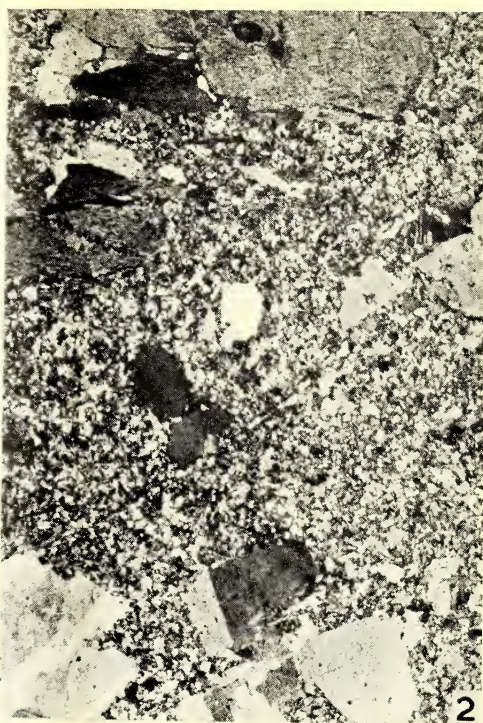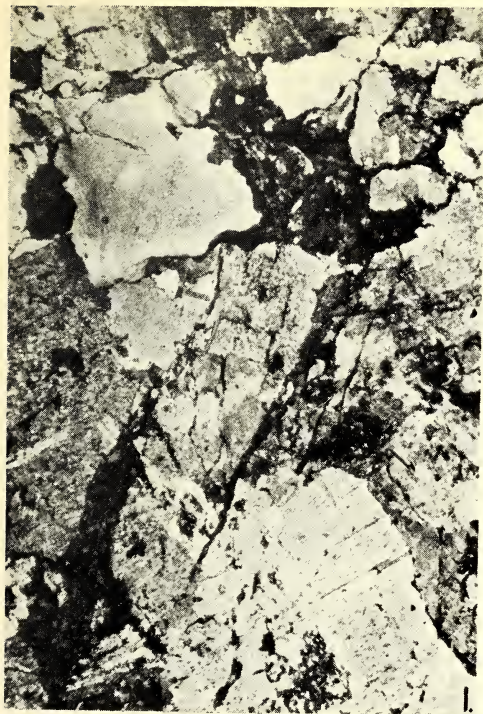
dolomitic limestone and associated phyllite in Portion 103, Parish of Queanbeyan, from underlying phyllite and dolomitic lenses. For the most part the dolomitic mass has been recrystallized to dolomite-clacite marble without the development of other contact minerals. However, on the south-eastern end of the limestone lens (through a distance of 15 ft.) the dacite passes from unaltered dacite into altered dacite containing limestone xenoliths of 0·2 cm. diameter.

The altered dacite consists of feldspar, quartz, biotite, diopside, phlogopite and chlorite. The feldspar is generally sericitized, but two unaltered fragments are andesine. Quartz varies in abundance and is absent in the highly altered portions. The sub-idiomorphic, colourless diopside crystals frequently possess green outer borders. This green colouration may indicate a lime-rich rim. Xenoliths up to 5 mm. in diameter occur; they consist of calcite grains and fine felted crystals of wollastonite which curve around phlogopite and diopside. Some of the xenoliths are characterized by abundant diopside with acicular crystals radiating outwards from the pyroxene. This radiating colourless mineral is possibly tremolite or wollastonite.

The altered dacite passes sharply into a zone of periclase rock about 4 ft. wide and finally back into dacite.

The narrow band of periclase is pale green or light canary-yellow coloured with a massive subvitreous appearance. The rock is extremely fine-grained and consists of four minerals. The predominating periclase occurs as a granular isotropic mass in which is scattered a small proportion of flaky brucite. The other minerals are hydromagnesite and calcite, the latter generally veining the periclase. This rock has resulted from dedolomitization and is indicative of relatively high temperature alteration.

Barrack Creek Adamellite.

This Upper Silurian stock with small associated offshoots intruded Ordovician and Silurian sediments after the emplacement of the dacite intrusions, and extends southwards from the second milestone on the Queanbeyan-Royalla road for about one mile. Its western contact transgresses Ordovician sediments and is well exposed along an erosion gully parallel to the Queanbeyan-Royalla road near Barrack Creek. In the quarry on this western side, numerous joint planes with brown and green oxides cut through the variably grained rock. A mile to the south the intrusion is in contact with phyllite, the adamellite trending parallel to the prominent cleavage direction of 225°. Isolated pockets of adamellite occur in the phyllite a few feet from the contact. On the eastern side of the mass the exposures of the actual contact with dacite are very poor.

The main part of the stock consists of a medium-grained leuco-adamellite. The whole mass has been subjected to strains, so that no thin section lacks evidence of deformation. Quartz, orthoclase and oligoclase are the essential constituents of the adamellite; ferromagnesians are lacking and accessory minerals are sparse. Muscovite occurs in druses in the south-western outcrops. A severely crushed specimen (Plate III,-Fig. 1) from the central northern part of the mass possesses cracked quartz with undulose extinction, whilst the feldspars (orthoclase and oligoclase) are bent and have been separated with inter-granular shears. In addition the rock has been albitized, chloritized and epidotized.

Interesting changes of fabric have been studied on the western margin, where good exposures are available, and these changes are present around the whole mass. The marginal rocks are still extremely leucocratic and acid in composition. In the quarry, 100 yards from the contact, the rock appears in handspecimen to be porphyritic, with quite an appreciable variation in grainsize. Under the microscope, it is a crushed and recrystallized adamellite with patches of original quartz, orthoclase and oligoclase retaining their granitoid fabric, and

surrounded by a fine recrystallized groundmass of quartz and feldspar. The rock is albitized and silicified and numerous quartz veins are present (Plate III, Fig. 2). Approaching the margin the adamellite becomes finer grained and, at the margin, directly west of the quarry epidote is developed. A similar development of acicular epidote, and some ziosite, occurs on the eastern side where the adamellite is in contact with dacite. The original outline of the feldspar is emphasized by concentration of epidote prisms around the crystal boundaries. A strongly felsitic phase is found a quarter of a mile to the south of the quarry near the margin of the intrusion. This rock is characterized by strained, cracked and resorbed quartz crystals (diameter 1 mm.), weathered feldspar (andesine) surrounded by patches of clear albite? and a spherulitic aggregate of quartz and feldspar forming coronas around the altered quartz (Plate III, Fig. 3). Large flakes of an originally red-brown biotite are chloritized. Andesine boundaries frequently fade into the groundmass, whilst other portions of the boundary remain sharp and clear. The groundmass consists of feldspar, quartz, sericite, phlogopite and iron ore. Symplectic intergrowth of quartz and feldspar is a consistent feature of the rock. To the north at the contact of the adamellite, the marginal rock is essentially the same except that the groundmass is finer grained, the larger crystals are more rounded, and the spherulitic fabric is lacking (Plate III, Fig. 4). Along the southern section of the margin the spherulitic phase is combined with the development of new minerals such as diopside, epidote and phlogopite.

A white aplitic rock occurs near the south-west margin of the intrusion. It has a typical sacchoroidal texture and is composed of an allotriomorphic aggregate of orthoclase and quartz with druses of muscovite. A typical micro-pegmatitic fabric is developed between the quartz and orthoclase, and this is particularly well developed in the coarser glomero-granular aggregates which are surrounded by the finer mosaic of quartz and orthoclase.

Veins of mylonitized adamellite (see fig. B, Harker, p. 170, and fig. 8, Goodspeed and Fuller, p. 270) cut the main body dominantly in an east-west direction. It would appear that these fracture zones have acted as passages for the movement of solutions rich in sodium, aluminium and silica together with smaller proportions of calcium, magnesium and iron, since the adjacent crushed adamellite has been extensively replaced with epidote, chlorite and albite.

Nature of the Intrusion.

I believe the adamellite has intruded an anticlinal fold and the occurrence of sediments within the adamellite boundary suggests that part of the roof of the intrusion is exposed. In the south and east the country rocks curve in conformity with the adamellite margin, and their dips are outward at steep angles for some distance. The strained and severely crushed nature of the adamellite indicates that continuing crustal movements in the later part of the Upper Silurian fractured the consolidated adamellite and that the deep-seated mass has come in contact with the Ordovician-Silurian sediments partly as a result of faulting. The lack of accessory minerals, and the recrystallization phenomenon towards the margin of the intrusion (Plate III, Fig. 2) may be in part due to this dynamic metamorphism of the intrusion.

The Barrack Creek Intrusion may be possibly an acid differentiate of the Murrumbidgee batholith since this acid stock has features somewhat similar to a very acid aplite gneiss near Cooma (Browne, 1931), which is a " marginal development of the Upper Murrumbidgee batholith injected during the epoch of folding that closed the Silurian period ".

The final stage of igneous activity is represented by numerous andesitic dykes, consisting of plagioclase phenocrysts set in a feldspathic groundmass.

In the south-eastern part a dyke trending east-west crosses the old Royalla road and can be traced into the western part of Portion 103, Parish of Quean-beyan. It is of interest because, in addition to oligoclase phenocrysts, xenocrysts of quartz with reaction rims in varying stages of development occur. It some cases the quartz has completely reacted and is represented by idiomorphic pyroxene, epidote and chlorite. Of other minerals, pseudomorphs of hornblende are filled with small magnetite crystals, whilst plagioclase has been albitized. The composition of the dykes further to the north is essentially the same, except that xenocrysts are absent.

The andesitic dykes crossing the adamellite have escaped most of the crushing movement but they possess strained xenocrysts which have been derived from the deformed adamellite, and in consequence it appears that they were injected after crushing of the adamellite, towards the close of this fracturing process.

SUMMARY.

An outline of the sequence of Ordovician and Silurian sediments is given; the Lower Silurian Camp Hill Sandstone overlying the Upper Ordovician Acton Shale with marked disconformity.

Sheared Silurian dacites outcropping on the eastern portion of the area are considered as mainly intrusive in character, whilst the suite of dacitic, rhyolitic and pyroclastic rocks occurring on the western portion suggests a volcanic series possibly Devonian in age. The locally mylonitized adamellite of Upper Silurian age invading Ordovician and Silurian sediments possesses a marginal felsitic phase and the intrusion has come in contact with adjacent rocks partly as a result of faulting.

Note is made of the occurrence of periclase rock resulting from the contact alteration of dolomitic limestone by Silurian dacite.

ACKNOWLEDGEMENTS.

EXPLANATION OF PLATE III.

Fig. 1.—Crushed adamellite with cracked quartz and feldspars; epidote and chlorite infilling the cracks. ×25.

Fig. 2.—Marginal phase of the intrusion. Crushed, recrystallized adamellite with patches of original quartz, orthoclase and oligoclase surrounded by a fine recrystallized groundmass of quartz and feldspar. Crushed nature of the rock is indicated by the dark lines crossing the slide. ×25.

Fig. 3.—Felsitic phase of the adamellite in contact with Muriarra shales on the western margin. Rounded quartz crystals are surrounded by a spherulitic aggregate of quartz and feldspar. Andesine crystals are adjacent to symplectic intergrowths of feldspar and quartz. ×25.

Fig. 4.—Altered marginal rock at the contact of adamellite with Ordovician pelite. Large corroded quartz crystals and altered feldspar are surrounded by a very fine-grained groundmass. ×25.

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PLEISTOCENE GLACIATION AND THE GREY MARE RANGE.

By A. S. Ritchie.
Newcastle University College,

and J. N. Jennings.
Australian National University.

Abstract.

The impact of Pleistocene glaciation on the Grey Mare Range is described from observations made during a brief ground survey. The conclusion reached is that the Grey Mare Range, contrary to previous opinions, escaped almost entirely the glaciation which left its clear mark in the mountains on the Main Range. The possibility of two small cirque glaciers is all that can be drawn from the evidence obtained.

Introduction.

The impact of Pleistocene glaciation on the Kosciusko highland has been of the lightest ; both erosional and depositional effects are weak in comparison with most glaciated areas. Combined with this obstacle to the complete understanding of glacial influence on the regional physiography is the further difficulty arising from the geological structure of the area ; the ranges are largely developed on granites and associated coarse-grained acid plutonic rocks, and under a wide range of climatic conditions these rocks tend to assume rounded landforms which in some degree at least simulate certain glaciated features. Furthermore, in these rocks subsurface weathering produces spheroidal boulders set in a matrix of sand and finer residual material with few fragments of intermediate size. The unrotted cores are readily isolated and accumulate at the surface in such a manner as to make confusion possible with glacial moraine, especially under solifluction conditions.

It is little wonder then that the exact extent of former glaciation in the Kosciusko area is still not fully determined. In this context, W. R. Browne (1952) has recently attempted to map these limits more adequately than had been done previously. In doing so he naturally extrapolated from his own and other worker's results in the better known parts into areas less accessible and less studied. This extrapolation relied partly on the mapping of cirques from air photographs, but he also employed the lowest known occurrence of glacial action at 4750 ft. (1448 m.) as a means of mapping the approximate maximum extent of former glaciation. It is clear, of course, that his essay is bound to be subject to modification in the light of detailed fieldwork. The margin of any icecap will not follow a contour ; on the one hand the firnline will vary in height through a region of even moderate size under the influence of general climatic factors and, on the other hand, ice lobes and outlet glaciers will project to various levels below the firnline under the control of ice supply and local topography. This is illustrated, for example, in the case of the Vatnajokull icecap in Iceland (Ahlmann, 1937), where the firnline varies from 700 m.

(2298 ft.) to 1600 m. (5250 ft.) in a distance of some 100 km. (63 miles) and the margin of the ice varies from virtually sea level to 1400 m. (4593 ft.).

The Grey Mare Range falls within Browne's maximum limit of glaciation and a number of cirques in the range are also indicated on his map. W. B. Dallwitz (1948) has also suggested that the range was glaciated; indeed he considered that certain boulder deposits at quite low levels in Errol's Creek and Bogong Creek were possibly of glacial origin. The writers of this note recently made as thorough an examination of this range as a short stay (20–28 November, 1954) permitted, and came to a different conclusion. The lower and middle slopes of the range appeared to be entirely the product of fluvial action and normal subaerial weathering, with the exception of some incipient solifluction terracing. At higher levels there is indeed a rounding of some valley-heads, though most retain the funnel-shape characteristic of fluvial action. There seems no reason to think that most of the more bowl-shaped valley and gulley heads are other than nivation hollows; it should be remembered that the dimensions of nivation hollows can be quite large (Lewis, 1936). Although the formation of some of the smaller nivation hollows of the Grey Mare Range may still be going on, in the main they are thought to belong to previous more severe climatic conditions. The wooded hollow at about 5250 ft. (1600 m.) on the east face of Grey Hill (grid reference S.M.A. sheet 286142 B 287·6; 142·4*) is an example of an inherited nivation feature. In addition, steps in certain valley floors (e.g. S. of Strumbo) seems more likely to be of structural origin than due to glaciation, since similar steps are to be found on spurs and the divide itself. These features may be the expression of flat-lying joint planes in the igneous mass.

The largest catchment-area above the 5400 ft. (1644 m.) level on the range is perhaps that of the Cyclone Creek; its several sources lie under hills rising to about 6000 ft. (1829 m.). Conditions here, we considered, were distinctly favourable for the accumulation of ice during a glacial period. Yet a careful study of the valley down to the upper limit of rejuvenation revealed no morainic matter, and no other features which could not be explained by stream action or nivation. Two possible exceptions to the general absence of glacial features in the whole area were observed. On the south-eastern face of Grey Mare itself, 6137 ft. (1870 m.) there is a shallow amphitheatre with an inclined floor, which is regarded as an incipient cirque (grid reference S.M.A. sheet 286142 B 288·3; 144·2†); the evidence for this is the presence of a spread of superficial deposits, disposed in a series of irregular shelves ending abruptly at about 5700 ft. (1707 m.) above a V-shaped valley; these deposits are regarded as moraine. In the experience of one of the writers (J.N.J.) the whole landform was very similar to a secondary cirque in the side of a larger cirque, Coire an Coirein Lochain, on Beinn Bhreac, Isle of Arran, Scotland. The other author saw in this cirque a strong resemblance to some he has described in the Granite-Peaks area (Ritchie, 1952). The second extraneous feature lies on the south; eastern side of Grey Mare Bogong (grid reference S.M.A. sheet 286146 B 290·3; 148·2) and consists of a fairly well developed cirque-like landform, with a flattish floor and a lip at 5500 ft. (1676 m.) modified by stream gullies. The presence of many rocky knobs and crags on the walls of this amphitheatre suggested a glacial cirque rather than a nivation hollow with its generally smooth sides. It is to be noted that certain common features in the sites of the two possible cirques would favour glaciation. They lie at high levels, they are on the lee side of the range in relation to the main snow-bearing winds, they face south-east, which allows some shade from the sun. The Grey Mare

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* 237201 on Military 1 mile sheet 795, zone 7 (Kosciusko).

† 251231 on Military 1 mile sheet 795, zone 7 (Kosciusko).

Bogong cirque has also the advantage of a fairly large supply area above it at the highest possible levels.

These views as to the lack of glacial effects at the higher levels were in conflict with Dallwitz's tentative interpretation of certain features he observed at lower levels in the Errol's Creek and Bogong Creek valleys on the western flank of the Range (Dallwitz, 1948). For this reason Dallwitz and Jennings went over this ground again (March 29, 1955). The most significant of these features are undoubtedly the boulder ridges near Dallwitz's station 12A2 in Errol's Creek (grid reference Military one Mile Sheet, 795, Zone 7 (Kosciusko), 193171). For about half a mile between the altitudes of approximately 3400 ft. (1036 m.) and 3000 ft. (914 m.) the young, V-shaped valley of Errol's Creek takes on a special character. Here there is a definite and continuous aggradational floor to the valley, as wide as 150 yards in places, abutting abruptly against the steep valley walls. This floor retains a steep slope down the valley, though the longitudinal profile is steeper both above and below. The detailed nature of this alluvial floor is not everywhere readily discernible through the presence of much dense scrub and close stands of tree fern beneath the high forest of gums. However, over much of it there are ridges of granitic boulders up to 6 ft. in length, running along the valley. They may stand as much as 15 ft. high. There is only one such ridge in places, certainly two in other parts and possibly more side by side. As they have none of the hummocky irregularity of moraine and do not exhibit any tendency to aggregate in sporadic masses or in ridges transverse to the line of the valley, it is now considered that the previous suggestion of a morainic origin must be abandoned and that the ridges must be entirely of fluvial construction, the depressions between and beside them representing former watercourses of a shifting and braided nature. Nevertheless, Errol's Creek does not now appear to be moving boulders of the size and in the quantity it must formerly have done to have built these ridges. The tall forest cover found on all these ridges is also evidence of a change of conditions. It is thought, therefore, that these features are inherited from a past phase of periglacial conditions in the upper basin of the creek, when severer climatic conditions enforced a lower tree-line, leaving the soil and rock mantle above more open to the attack of run-off, and when snow melt was much more concentrated in a spring thaw period, giving rise to more markedly torrential flow at that time. It is possible that the total precipitation may also have been greater in such a phase. Periglacial conditions here would, of course, coincide with glacial conditions in the main range.

The conclusion proffered then is that the Grey Mare Range, contrary to some previous suggestions, escaped almost entirely the glaciation which left its clear mark in the mountains on the main range. This may have been due to a rising firnline to the north and west and to the limited areas at really high levels on this range. Possibly there were two very small cirque glaciers in locations most favourable to glaciation. If the range were glaciated in any previous Pleistocene glaciation, the effects have been so destroyed by later normal erosion as to be unrecognisable. On the other hand, some effects of nivation and other periglacial processes in the Range have been pointed out. Such effects are to be expected in other areas marginal to the Kosciusko region subjected to true glaciation in the Pleistocene.

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of transport to the Grey Mare Hut, and of the Bureau of Mineral Resources, Geology and Geophysics in providing transport to Bogong Creek is gratefully acknowledged also.

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FOR

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PART III (pp. 131-156)

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EDITED BY

F. N. HANLON, B. Sc., Dip. Ed.

Honorary Editorial Secretary

THE AUTHORS OF PAPERS ARE ALONE RESPONSIBLE FOR THE
STATEMENTS MADE AND THE OPINIONS EXPRESSED THEREIN

THE PALÆOZOIC ROCKS OF THE WISEMAN'S CREEK-BURRAGA AREA, N.S.W.

R. L. STANTON.

With four text-figures.

CONTENTS.

ABSTRACT.

The area considered lies just to the south of Bathurst, and consists of metasediments and intrusive igneous rocks of Palæozoic age, together with isolated residuals of Tertiary basalt flows. The sediments—shales, greywackes, tuffs and minor limestone—were deposited in a eugeosynclinal enviroment and are probably of Upper Ordovician and Lower Silurian age. Well-developed foliation in the " porphyroids " and in some of the granitic rocks indicates that these assumed their present positions prior to or during the Bowning orogeny, during which the sediments were folded and metamorphosed to biotite grade. A small area of granodiorite occurring to the east of Burraga is quite free of foliation, and is thought to be comagmatic with the main Bathurst-Hartley batholith, and hence of lower Carboniferous age. Although not considered in the present study, several Tertiary basalt flows, with associated greybilly, occur as residuals in higher parts of the area.

INTRODUCTION.

As shown in Fig. 1 the area considered extends in a north-south direction from the small village of Cow Flat to the village of Burraga and, in an east-west direction, from Wiseman's Creek to Caloola. The writer was introduced to it in 1948 when, as a mining geologist with Broken Hill South Ltd., he carried out a detailed investigation of the Lloyd Copper Mine workings at Burraga.

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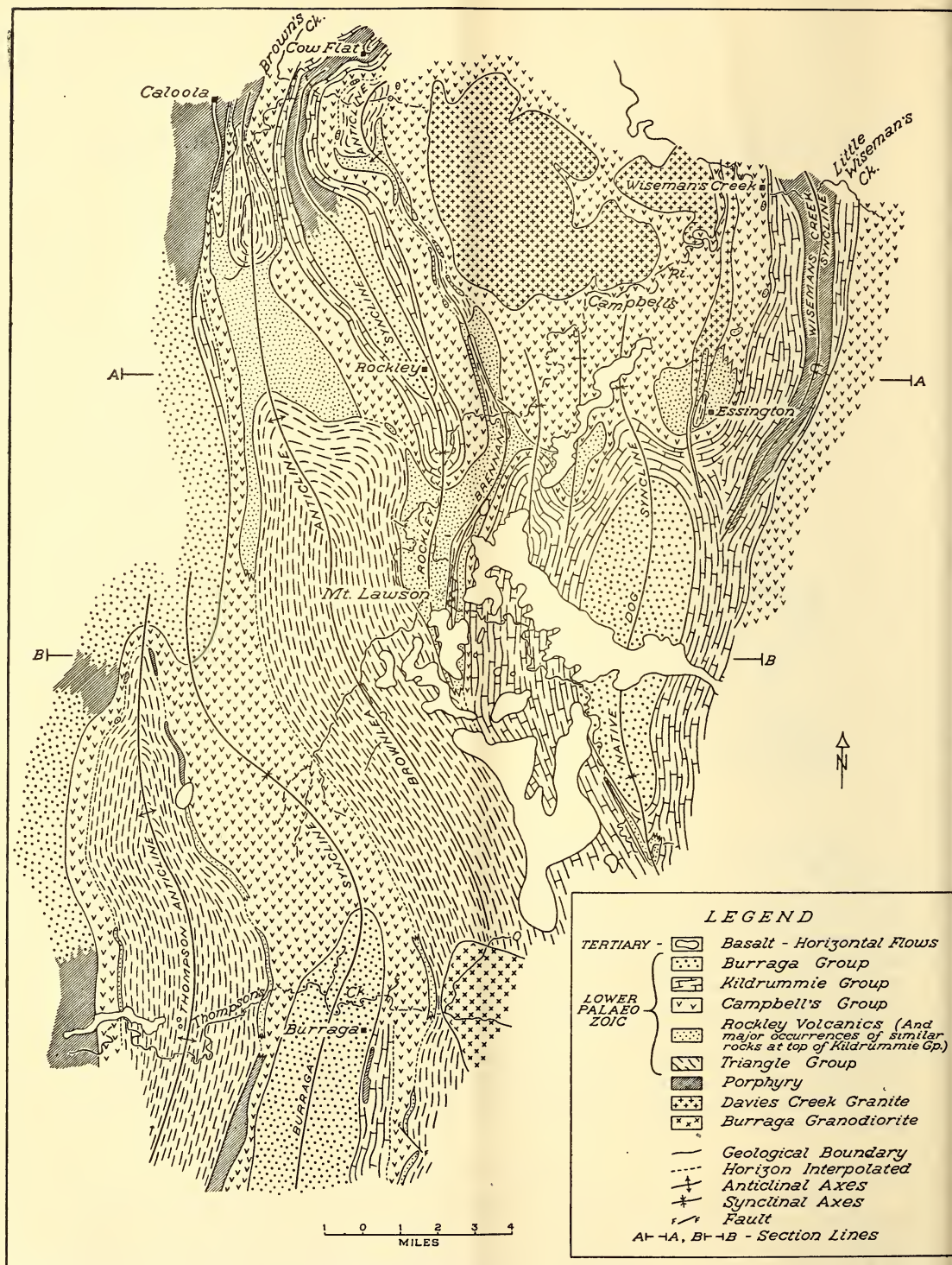
Text-fig. 1.—Geological map of the area.

While making a brief reconnaissance in connection with the mining work, it became clear that other orebodies in the Burraga region were associated with geological features similar to those found at the Lloyd Copper Mine, suggesting the possibility of a regional pattern of mineralisation within the Lower Palæozoic rocks of this part of New South Wlaes.   One of the more important aspects of the subsequent regional study of mineralisation was the determination of any possible spatial relationships between the distribution of the orebodies and their geological setting.   This has involved the geological mapping of an area of approximately 600 square miles, the results of which are now presented.

Prior to this investigation, little geological work had been done in the area. In 1937 J. A. Dulhunty mapped an area of about 30 square miles round the village of Rockley, but this work has never been published and the present writer has had to remap the area.   Apart from scattered observations by Carne (1908) and Carne and Jones (1919) (in connection with some of the copper and limestone deposits of the area), nothing has been published concerning the geological features of the rest of the area.

PHYSIOGRAPHY

The area mapped extends into both the Macquarie and Abercrombie drainage systems, Campbell's River being a unit of the former and Thompson's Creek a unit of the latter.

· The streams of both systems are at present dissecting a plateau surface, isolated remnants of which stand at 3,300 ft. to 3,500 ft. above sea level.   The Macquarie-Abercrombie divide, which rises to about 3,500 ft. is an undissected portion of the older plateau, and has been referred to as the " Abercrombie Plateau " by Dulhunty (1937).   It is the only true peneplain level in the area, and probably developed in late Cretaceous or early Tertiary time.   The present maximum relief for the district as a whole is approximately 1,000 ft.

The streams of both systems pass through greatly contrasting valley types, the form of these being largely determined by the nature of the rocks in which they have been developed.   Apart from the mature upland topography of the divide—the type usually found on plateau surfaces above the head of rejuvenation—the more mature parts of the region are those in which the soft, easily weathered volcanic rocks occur.   Areas of silicified slates, granite and, particularly, " porphyroid " are normally youthful, and are characterised by rugged, uncleared country and deep, steep-sided stream channels.

STRATIGRAPHY.

The total thickness of sediments exposed in the area is rather more than 30,000 ft.   The whole sequence is conformable, and no basement of sedimentation has been found.   By far the dominant rock types are shales and greywackes, though variation in these, and the occurrence of the volcanic rocks and limestones, indicate a division of the sediments into five distinct units.   These are as follows :

	Name		*Approximate Max. Thickness*
Lower Silurian ?	Burraga Group	..	.. 4,500' plus
	Kildrummie Group	..	.. 6,000'
	Campbell's Group	..	.. 9,000'
Upper Ordovician ?	Rockley Volcanics	..	.. 5,000'
	Triangle Group	..	.. 10,000' plus

These stratigraphical divisions have been named according to the Australian Code of Stratigraphic Nomenclature (Raggatt 1950), the names selected being those of two villages, two streams, and a well-known estate, in the vicinity of which the relevant formations outcrop. The ages assigned to them are very tentative, and are based on correlations, which at this stage are of doubtful reliability, with rocks of known age in adjacent localities. It is clear that there is scope for considerable palæontological work in the area, and there can be no precise estimates of age until this is done.

(1) *The Triangle Group* :

This group has been so named as it was first examined in good exposures along Triangle Creek, about five miles south of Rockley Village. It is definitely known to underlie the other sediments over the whole area studied, and appears in the cores of all eroded anticlines. As its base has not been found, no estimate can be made of any variations in its thickness. The maximum observed thickness is, however, approximately 10,000 ft.

The group is made up of low-grade metamorphic products of predominant shales, greywackes, isolated chert lenses and very minor tuffaceous bands. The lowest parts revealed are of fine shales, in which bedding is absent or poorly developed. In the middle part of the section the bedding becomes a little more prominent and greywackes appear. In this part, too, graded bedding is fairly common. At about 2,500 ft. from the top of the group the bedding becomes much more prominent, and noticeably coarser bends develop. Where rock-fragments occur they are angular to sub-angular and are of shale, slate and very subordinate quartzite.

Much of the coarser material of the higher parts consists of felspar and quartz particles set in a shaly matrix. Felspar is dominant among the particles, is of approximate composition An30, and shows little rounding and no evidence of strain. Quartz is noticeably poorly developed, more than two or three grains rarely occurring in any one thin section examined ; it shows fair rounding and well developed undulose extinction. It is therefore likely that the quartz has been involved in at least one earlier cycle of sedimentation, and in a period of metamorphism which the felspar escaped. The matrix is normally composed of very fine quartz and felspar, chlorite, fine epidote and carbonate cement.

In some parts of the area—e.g. in the thin strip of Triangle rocks revealed in the core of the Brennan anticline just to the east of Mt. Lawson—the shales of the upper part of the group contain a high proportion of carbonaceous material. Variation in the carbon content of the fine bedding-lamellæ sharply delineates these, and in thin section the carbonaceous rocks usually show clearly defined and delicate bedding. In the locality cited these shales also contain abundant pyrrhotite (Stanton, 1955). Flecks of this mineral are usually flattened parallel to the bedding of the shales, and when viewed at right angles to the bedding, are generally in the form of elongated, spindle-shaped bodies up to $4 \cdot 0$ mm. in length.

(2) *The Rockley Volcanics* :

The rocks of this formation are readily distinguished in the field, and serve as a useful horizon in mapping. Their maximum development occurs just to the west of Rockley village, where their thickness is approximately 5,000 ft. For most of the area it is much less, and it is extremely variable. In the northern half of the mapped area the formation is well developed in the west, thins out towards the east, and then thickens again. From north to south the volcanics lens out in about the middle of the area. They then develop again, though on a less extensive scale, in the south and south-western portions of the area.

The boundary between this formation and the Triangle Group is conformable. Normally there is a sharp lithological break in going from one to the other, but this is not always so, and in a few localities the change is gradational over a range of up to 300 ft.

The formation consists almost entirely of regionally metamorphosed andesitic pyroclastics. Massive rocks—flows or sills—occasionally occur, but are very subordinate to the fragmental rocks. Here and there the tuffs grade into small shale lenses. The pyroclastic rocks are for the most part fine, but a few coarse lenses occur, where the fragments (usually sub-angular) may be up to approximately one foot in diameter. The original composition and texture of the tuffs has been modified by subsequent alteration and metamorphism but it is probable that they consisted mainly of hornblende, oligoclase and andesine felspar, and a little augite and iron oxide. Almost all thin sections show heavy chloritisation, both of the larger fragments and the fine groundmass. In some specimens a carbonate cement is prominent, and others show fair development of fine authigenic quartz. Small cavities may be filled with carbonate, one or more varieties of chlorite, and epidote.

Whether the massive rocks are flows or sills is difficult to determine. It seems significant that they have been found only in the volcanic formation ; were they intrusive it is likely that they would have been transgressive at least in some small part, and that they would have been found in the adjacent sediments, too. On present evidence it seems most likely that they are minor flows. As they have been more resistant to metamorphism than the fragmental rocks (see below), their original composition and texture are more easily determined. They are principally porphyritic hornblende-andesites, hornblende-augite andesites, augite-andesites and very minor basalts. Hornblende is normally colourless to pale green, though a brown variety is locally dominant. Augite is pale, and is the only pyroxene to have been detected. Plagioclase compositions vary in the calcic andesine-sodic labradorite range. Occasionally felspar laths and hornblende needles reveal good flow structures, and many of the rocks are glomero-porphyritic. In some instances vughs and filled cavities are common, and it is fairly certain that there has been considerable deuteric alteration and deposition similar to that in the tuffs. Quartz, chlorite, epidote and zeolites form the vugh fillings.

Much of the formation appears to be marine. Fragments of an Encrinurid trilobite have been found in the tuffs to the west of Rockley, and bryozoa can often be detected in thin sections. Aqueous deposition is also indicated by the occasional gradation of pyroclastic into bedded shaly sediments, particularly at the base of the formation.

(3) *The Campbell's Group* :

Although they are well developed over the whole area mapped, the rocks of this group appear most extensively along the northern part of Campbell's River, after which they are named. Transition from the Rockley Volcanics into the basal members of the Campbell's Group is normally sharp. Where the volcanics are absent, however, and the Campbell's Group lie directly upon rocks of the Triangle Group their base cannot be defined. Relationships between the three rock units is conformable. G. H. Packham (in personal discussion) has suggested that the rocks of the Campbell's Group may be of Upper Ordovician rather than Lower Silurian age.

The maximum thickness of the Campbell's sediments is approximately 9,000 ft., though variations in thickness are considerable. They comprise metamorphosed shales and sandy shales, tuffaceous shales, greywackes and conglomerates, and in many ways this group is very similar to the upper part

of the Triangle Group. In many exposures the basal members are well-bedded, slightly tuffaceous shales, though in the more western part of the area they are often coarse conglomerates. Higher in the section the bulk of the sediments are sandy and slightly tuffaceous shales, averaging coarser and more uniform than the lower group. At the top of the section a coarse greywacke forms a prominent, though discontinuous, band approximately 300 ft. thick.

Felspar is the most prominent detrital mineral, generally of oligoclase-andesine composition and in the form of stumpy, fairly angular grains. It is normally rather dusty and shows variable sericitization. Quartz is usually subordinate to felspar, varies from very angular to well rounded and shows undulose extinction. In the more tuffaceous members, tremolitic amphibole may form up to 15% of the rock. The fine matrix is normally composed of clay, fine sericite and chlorite, and some finer felspar, quartz and amphibole particles.

The Campbell's sediments differ from the earlier ones in that they contain abundant carbonate. This frequently cements together some of the coarser grains, and in some cases replaces felspar. Pyrite is also present throughout the group, and occurs as disseminate cubes averaging approximately 0·7mm. in diameter. There seems no doubt that this is of normal syngenetic origin.

(4) *The Kildrummie Group* :

The rocks of this group, although widespread, were first examined in good exposures on the Kildrummie Estate, about seven miles south of Rockley. It is after this property that the unit is named.

The group consists of limestones, dolomitic limestones, marls and shales. Its maximum thickness, shown along the headwaters of Campbell's River, is about 6,000 ft. The base of the group has been taken at the base of the lowermost limestone outcrops as, where no actual limestone occurs, it is difficult to draw a boundary between this and the Campbell's Group.

Although the shales of the group are well developed over the whole area, formation of massive limestone is not nearly so widespread. The area containing most limestone is a fairly well defined strip, running more or less south-east from Cow Flat, through Rockley down to the Riverview Estate. Limestone occurs to the west of this—e.g. at Caloola—but far less abundantly. To the east it thins out quickly, and is absent on the eastern limb of the Brennan anticline. It occurs again near Essington and Wiseman's Creek, but much less abundantly than in the Cow Flat-Riverview zone. Limestone is conspicuously absent in almost the whole of the southern part of the area, only starting to appear again to the south-east of the Lloyd Copper Mine.

Much of the limestone is clearly coralline. *Halysites*, *Favosites*, *Heliolites* and other genera are common. Brachiopods, including *Pentamerus knightii*, are locally abundant. Bedding in the limestone is variable—from excellent to absent. Generally the very finely bedded material is more or less devoid of fossils. The principal impurity in the limestone is fine shale, into which the former eventually grades. Some carbonaceous material, and the usual disseminated sulphide, have been found in the shales.

(5) *The Burraga Group* :

This was first examined in the vicinity of Burraga village, after which it is named. As the top of the unit is not exposed, it is not possible to estimate any variations in thickness. The maximum thickness observed, however, is approximately 4,500 ft.

The group is conformable with the underlying Kildrummie rocks, and comprises regionally metamorphosed greywackes (with minor associated

conglomerate) of dominantly volcanic derivation, shales and andesitic tuffs, the former greatly predominating. Lithology of the base of the group is rather variable. Frequently the change in sedimentation has been accompanied, and in some cases anticipated, by the deposition of andesitic tuffs, similar in all respects to those of the Rockley Volcanics. Where these occur well below the typical greywacke of the Burraga Group, it seems best to assign them to the upper part of the Kildrummie Group. On the other hand, in many parts, the andesitic tuffs are intimately related to the greywackes, and can only be assigned to the higher group. However, they are not important in the delineation of the stratigraphical boundary in question—the change in conditions of sedimentation is clearly marked by the initial development of the greywacke, which is by far the dominant and most characteristic rock type of the Burraga Group.
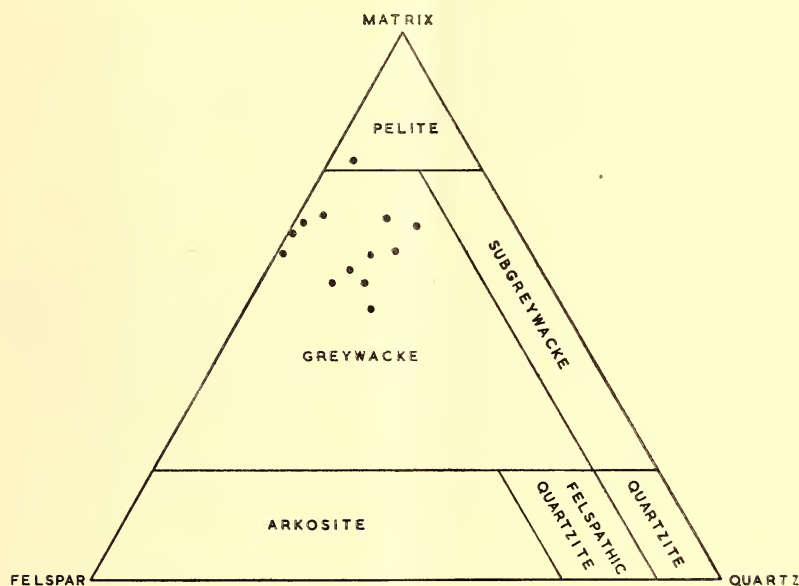
Text-fig. 2.—Composition of the greywackes of the Burraga Group. Classification after Pettijohn.

The important features of the greywackes are clear in hand-specimen. The abundant matrix is a light grey-green, and is studded with numerous white and pale pink felspars amd much less abundant quartz grains. Normally the rocks are quite massive, though they occasionally show graded bedding. Under the microscope they are seen to consist of matrix, felspar and quartz, in order of abundance, together with minor amounts of epidote, iron oxide, hornblende, carbonate and sulphide. These rocks appear so uniform, and the three main constituents so clearly defined, that a number of micrometric analyses have been carried out to determine the proportions of felspar, quartz and matrix occurring in them. Thirteen specimens, each as representative of their occurrence as possible, were selected for this purpose from outcrops in different parts of the district. Micrometric analyses of these have been plotted on a triangular diagram (Fig. 2). As can be seen, their field falls almost entirely within the greywacke field of Pettijohn.

It is probable that at least most of the felspar, and the minor hornblende, of these greywackes are of volcanic origin. The lack of rounding of the felspars seems to indicate that they could not have taken part in an earlier cycle of

erosion, and hence that they could not be the result of erosion of earlier sediments. The quartz grains frequently show extreme angularity, suggesting that they, like the felspars, are undergoing their first cycle of erosion. However, their possession of undulose extinction indicates their having undergone strain which the felspars have not, and suggests that the two have been derived from different sources. It is tentatively suggested that whereas the felspars had a volcanic source, the quartzes have probably been derived from metamorphic rocks.

GEOLOGICAL STRUCTURE.

The major fold structures of the area conform with the regional pattern in this part of eastern New South Wales, and are ascribed to the general east-west compression developed during the Bowning orogeny. Three pronounced features of the general structure are :

(a) A prevailing northerly plunge of the fold axes (see Fig. 4).

(b) An increase in complexity of folding from south to north.

(c) The rarity of faults ; only three faults of sufficient size to show on the map have been found, and even these are very minor structures.
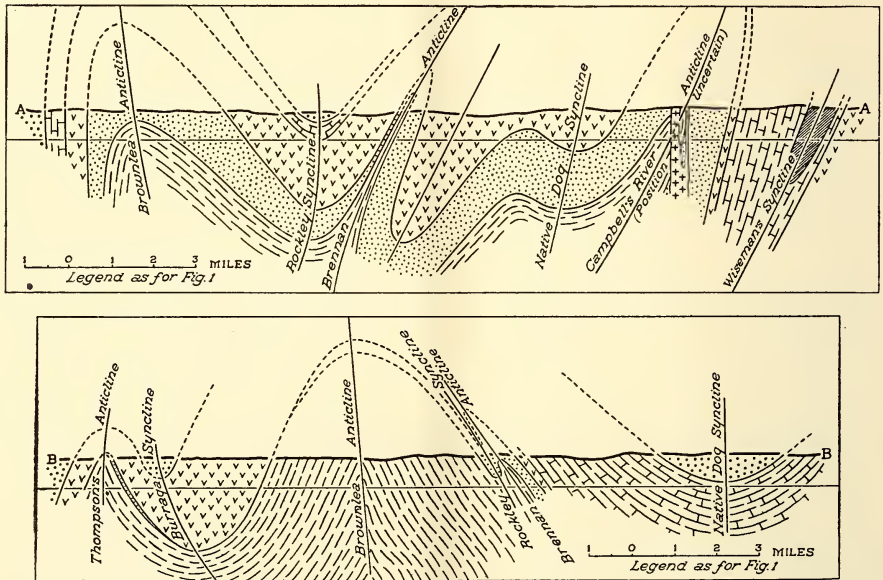
Text-fig. 3.—Vertical sections through A–A and B–B as shown in Text-fig. 1.

It seems likely that during folding the rocks at present exposed were in a relatively deep zone characterised by flexing rather than breakage, and that, as a result of the regional plunge, the structures in the northern part of the. area became tighter and more complex than those in the south.

The principal features of each of the major folds are :

(1) *The Thompson Anticline.* This occurs in the south western part of the area, where it has been traced for about fourteen miles. In section it is an upright, symmetrical fold. Its axis, which trends almost north-south, is flexed slightly to the north-west in its central portion. Plunge is moderate and even to the north (Fig. 4).
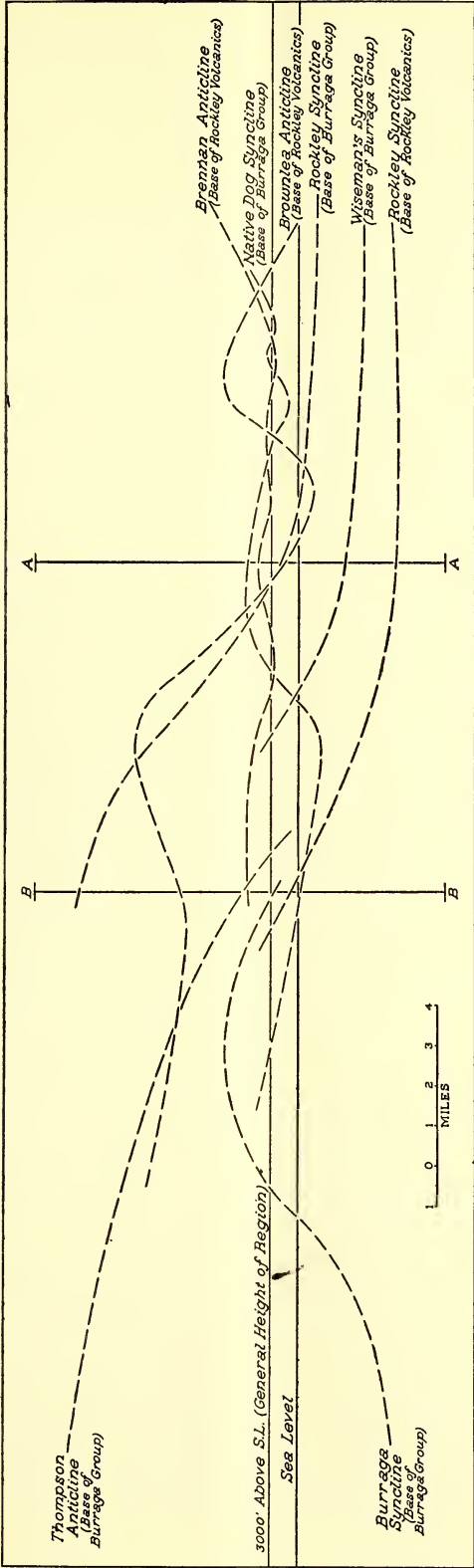
Text-fig. 4.—Projection of fold axes on a north-south vertical plane. The traces of sections A–A and B–B are shown.

(2) *The Burraga Syncline.* As would be expected, the trend of this fold roughly parallels that of the Thompson Anticline, though it shows a much sharper westward change in trend than the latter structure. The fold is fairly open, but is probably slightly asymmetrical, the axial plane dipping to the west at its southern end, and to the east at the northern end. Plunging of the axis is of about the same degree as in the Thompson Anticline, and down both to the north and south.

(3) *The Brownlea Anticline.* This structure has a greater observed length than any other in the area, and has been traced from the vicinity of Cow Flat in the north to just east of Burraga in the south—a distance of about twenty-four miles. In the north it appears as a slightly asymmetrical fold (Fig. 3) which broadens and flattens out as it trends in a south-south-easterly direction. Except for very minor flexing, the axis shows a constant NNW trend. It undulates, as shown in Fig. 4, giving rise to an elongated dome structure just to the south-east of Caloola, and to a pronounced " saddle " in the Rockley Volcanics to the west of Rockley. The structure appears to be rising at the southern limit of observation.

(4) *The Rockley Syncline.* Although possessing a general NNW trend, this fold is marked by an elongated S shape when viewed in plan ; to the south its trend changes to almost due north-south, while in the north it shows a sharp deflection to the north-east. At its northern extremity the fold is tight and overturned to the east, the axial plane dip being about 60° in a westerly sense. Moving south, the fold opens, and becomes more or less vertical, and the axis rises. By the time Section B-B (Fig. 3) is reached, the structure has become tight again, and the axial surface has assumed a clear easterly dip.

(5) *The Brennan Anticline.* This is by far the tighest structure in the area. For about two miles south of Cow Flat it is quite open and symmetrical, with a very slight overturning to the east. It quickly pinches, however, and appears in section as a sharp, overturned fold with parallel limbs and a dip of between 50° and 60° in a westerly sense. Along the whole of its southward continuation it is in this form, with a trend closely paralleling that of the Rockley Syncline.

Apart from its tightness, the most notable feature of the fold is the variation in the attitude of its axial surface. In the north, this dips westward, but it gradually changes and achieves a vertical attitude between Sections A-A and B-B ; there is then a gradual reversal, and near Mt. Lawson the axial surface dips at about 60° east. Thus the axial surface has a marked " propellor blade " form.

When viewed in projection (Fig. 4) the axis of the fold is gently undulating.

(6) *The Native Dog Syncline.* This structure can be identified definitely only to the south of Campbell's River. It is a broad, open fold and its axis, with minor deflections, trends almost due north-south. Plunging of the fold has produced a neat basin structure, shown up clearly by the greywackes of the Burraga Group, near the eastern edge of the map.

(7) *The Campbell's River Anticline.* There is little direct structural evidence for this fold. It is, however, a structural necessity between the Native Dog and Wiseman's synclines, and its existence is compatible with the observed outcrop pattern. What evidence there is suggests that it trends almost due north-south, and that it is overturned to the east.

(8) *The Wiseman's Syncline.* This small syncline compares in tightness with the Rockley Syncline in the neighbourhood of Cow Flat. As with that fold, the Wiseman's Syncline has more or less parallel limbs, and is slightly overturned such that its axial surface dips very steeply to the west. In projection, too, the axis of this fold is very similar to the northern part of that

of the Rockley Syncline in that it is horizontal in the north, and begins to rise in the south at much the same angle.   In plan the axis of the Wiseman's Syncline trends almost due north-south to the line of Section A-A, where it changes to a south-south-west direction.   This is retained as far as the fold can be traced.

Matamorphism

All the folded rocks of the area have suffered regional metamorphism, and as a result now occur principally as phyllites and low-grade schists.

The important rock-groups, from the point of view of the development of distinctive metamorphic mineral assemblages, are shales, calcareous shales, quartzo-felspathic rocks and the andesitic volcanics.   These rocks clearly cover a fairly wide chemical range, and correlation of the results of metamorphism of all types seems to indicate quite conclusively that metamorphism over the whole area has been consistently of low grade.   If the pelitic rocks are taken as indicators, the highest grade reached is that of biotite.   Both muscovite-chlorite and biotite-chlorite assemblages (and their equivalents) occur, and hence both muscovite-chlorite and biotite-chlorite subfacies are represented.

As is clear from the account of the stratigraphy of the area, shaly rocks are by far the most abundant type; their metamorphism has produced rocks covering the range slate-phyllite-low grade schist.   The pelitic schists most commonly contain the assemblage chlorite-muscovite-quartz-epidote-albite. Elongated chlorite flakes are up to 1 mm. in length, and are usually pleochroic from bright green and blue-green to very pale green and almost colourless. Muscovite particles are of the same order of size as the chlorite.   Quartz grains rarely exceed 0·5 mm. in diameter, have typically crenulate boundaries and generally contain fairly abundant small flakes of chlorite and sericite.   Epidote occurs as fine granular aggregates, and as isolated grains up to about 0·2 mm. diameter.   Albite occurs as tabular crystals up to about 0·5 mm. in diameter. Variation of this assemblage is brought about by the appearance of biotite. Much of this is a green variety (pleochroic from pale brown to a dirty olive green), though where metamorphism has clearly been of biotite grade the latter is typically honey-brown to very deep brown.   The biotite occurs as stubby plates up to 0·5 mm. long.

Regional metamorphism of the calcareous rocks seems to have caused little more than the recrystallization of the limestones and dolomitic limestones, and the development of small clots of carbonate in the calcareous shales.   In the latter the assemblage calcite-chlorite-quartz is usual.

In the quartzo-felspathic rocks, the abundant plagioclase has suffered varying degrees of decomposition.   Where changes have not been more intense, the felspar is invariably clouded—presumably the first stage of low-grade metamorphism.   The most common changes are to chlorite, epidote, sericite and carbonate.   The degree of replacement of felspar by these varies up to almost complete pseudomorphism.   Quite frequently, where the felspars are zoned, decomposition has followed some zones selectively—e.g. epidote—and chlorite-rich zones developed in this way are quite common.   Apart from very minor cataclasis, the quartz particles have been affected.   The matrices of these rocks are normally shaly, and hence the assemblages developed in them are similar to those of the pelitic rocks.   In some instances, matrices are rather tuffaceous, and in such cases fine, rather fibrous actinolite occurs.

It is clear that the andesitic rocks have suffered deuteric alteration as well as low grade regional metamorphism; the first is particularly obvious in the non-fragmental members, in which vesicles are commonly filled with chlorite, epidote and carbonate.

The felspars of the andesites and andesitic tuffs have been replaced to varying degrees by microgranular aggregates of chlorite, sericite, epidote, carbonate and occasionally actinolite and biotite. The pyroxenes are replaced to a minor extent by chlorite, and commonly by uralite. Complete pseudomorphs of augite phenocrysts by amphibole are fairly frequent, and may be up to $0 \cdot 8$ mm. across. In many sections the amphibole shows a pronounced tendency to shred, or to develop fibrous outgrowths which form more or less in the foliation planes. These outgrowths, which appear initially simply as ragged edges of amphibole grains, penetrate not only the groundmass of the rocks, but also other, differently oriented, amphiboles, and felspars. Metamorphism of the fine groundmass has developed abundant chlorite, epidote and fibrous actinolite, with minor amounts of carbonate, quartz, albite and biotite.

The " Porphyroids."

These rocks have the appearance of regionally metamorphosed quartz and quartz-felspar porphyries. In Australian geological literature and mine reports rocks similar in many respects to these are usually referred to as " sheared porphyries ", and they are, of course, known in a number of localities in the Lower Palæozoic rocks of Eastern Australia. A consistent feature of them is that they are conformable with the sediments among which they occur. They show a limited variation in petrology, and in some cases they appear to be fragmental.

In the Bathurst area such rocks occur principally within, or as stratigraphical equivalents of, the Rockley Volcanics and the Burraga Group ; very minor occurrences are found in the Triangle Creek and Kildrummie Groups. The types of sediments of which these igneous-looking rocks appear to be equivalents are thus andesitic volcanics, greywackes (of dominantly volcanic derivation), and to a limited extent, shales. To correspond with these three different sedimentary types are three different types of igneous-looking rock.

That these rocks are the result of igneous intrusion is doubtful, and in fact it seems likely that some of their present features result from metasomatism. A full consideration of this problem is, however, beyond the scope of this paper, and it is proposed to make it the subject of a future contribution.

Igneous Rocks.

Apart from the fragmental units already described, igneous rocks of three age groups outcrop in the area mapped. Of these, two are Palæozoic and one Tertiary. The last is represented only by isolated horizontal residuals of basalt flows, which appear to be essentially similar to those typically developed in many parts of the eastern highlands. Apart from the mapping of its boundaries, it has not been considered in the present study. Of the other two, one—the Davies Creek Granite—was emplaced prior to or during the main folding period. The other—the Burraga Granodiorite—is clearly of post-folding age.

(a) The Davies Creek Granite :

This outcrops as three separated masses in the northern part of the area.

One of these has a clear north-south trend, and traverses rocks of the Campbell's and Kildrummie Groups, and the Rockley Volcanics. At its southern end it divides into two narrow strips which gradually taper right out. The transgressive nature of this mass, and the lack of effect of physiography on its outcrop pattern, indicate a dyke form.

The outcrop patterns of the other two masses, on the other hand, frequently show distinct relationships with the topographic contours (this part of the area

was mapped using military base maps of 50 ft. contour interval) and the stream pattern. It is quite clear in many such cases that the base of the mass is at shallow depth and is horizintal, or very nearly so. Further, neither mass shows transgressive relationships with the sedimentary rocks. They are entirely surrounded by rocks of the Campbell's Group, and the strike of the western edge of the more westerly mass closely parallels the trend of the Rockley volcanics as they outcrop along the Brennan Anticline. The outcrop evidence strongly suggests, therefore, that the granite is here conformable with the sediments. Whether it was originally completely enclosed by sediments of the Campbell's Group, or whether it was emplaced along the boundary of that unit and the Burraga Group, could not be determined in the area mapped. Whichever of these has been the case, it is considered that these two more westerly masses form part of a sill, of unknown thickness, which was very possibly connected to the eastern dyke.

Most of the granite shows at least some foliation, though the intensity of this is rather variable. The most pronounced foliation is developed in the more westerly part of the western mass, possibly as a result of rather tighter folding in this area. Parts of the dyke, on the other hand, show very little foliation at all. As the directional structures in the granite conform with those in the adjacent sediments, it is concluded that emplacement of the former took place either prior to or during the folding of the latter.

In hand-specimen the body-colour of the rock is pink, the grains of orthoclase varying in length up to 5·0 mm., and averaging about 2·0 mm. across. Quartz grains up to 3·0 mm. across are usually obvious, and shreds and wisps of biotite are oriented in the foliation plane. Under the microscope the rock is seen to consist of orthoclase, quartz, biotite, plagioclase (albite where determinable), muscovite, epidote and iron oxide, in order of abundance. In some sections myrmeketic intergrowths are abundant, the plagioclase being riddled with the characteristic lobate patches of quartz vermicules. Much of the biotite shows pleochroic haloes. Foliation is usually apparent in the thin sections. The quartz shows undulose extinction and some granulation.

(b) *The Burraga Granodiorite* :

A considerable area of this has been covered in reconnaissance, and it is clear that the small area shown in the south-eastern corner of the map is merely a tip of a large mass extending away to the north, east and south of the present area. It is, in fact, likely that this mass will be found to be a part of the main Bathurst-Hartley batholith.

The granodiorite transgresses the strike of the sediments and, where observed to the east, has given rise to dykes which are clearly intrusive. It is therefore concluded that the main mass itself intruded the sediments as a magma. All outcrops are massive—there is no suggestion of the foliation so prominent in the porphyroids and the Davies Creek Granite. This, together with the other features of the field-occurrence of the granodiorite, indicates that its emplacement was distinctly post-folding.

In hand-specimen the general body-colour of the rock is light grey. Plagioclase, quartz and biotite are easily distinguished, plagioclase in grains up to·approximately 0·5 cm., quartz up to approximately 2·0 mm. and biotite up to approximately 1·0 mm. across. In thin section zoned plagioclase (variation in the oligoclase-andesine range) is the dominant mineral. Alkali felspar (almost entirely microcline) does not exceed about one-fifth of the total felspar content. Quartz constitutes about 15% of the rock. Biotite, which is pleochroic from light honey-brown to very dark brown, shows some tendency

to occur in clots. It is usually slightly altered to chlorite, and shows abundant pleochroic haloes. Muscovite also occurs, but is greatly subordinate to biotite. Iron oxides, apatite and a little epidote are accessories.

GEOLOGICAL HISTORY.

The earliest sediments—those of the Triangle Group—appear to have been derived principally from older, metamorphosed sediments. This is indicated by the rock fragments (shale, slate and quartzite) included in the upper members of the unit. The presence of abundant carbon in some of the shales near the top of the unit suggests that fairly intense organic activity prevailed at the time. Syngenetic iron sulphide, often associated with the carbonaceous rocks, has probably resulted from bacterial sulphate reduction (Stanton, 1955).

The crystalline character of the Rockley Volcanics indicates that these were terrestrial, but whether they were sub-aerial or redistributed cannot be determined. The presence of large angular volcanic boulders and the rapid thickening and thinning of the unit as a whole suggests that the present area was close to the volcanic source. The rocks of the Campbell's Group seem to have been deposited under conditions similar to those prevailing during the formation of much of the upper part of the Triangle Group, though the sediments are generally coarser in the higher group, and usually contain a little more volcanic material. The coarse greywacke at the top of this unit probably represents a final spasm of instability prior to the development of the stable conditions which permitted the formation of the limestones of the Kildrummie Group.

A pronounced change in sedimentation was ushered in by a resumption of vulcanism, which led on to the development of the extensive and very uniform felspathic greywackes of the Burraga Group.

Although the total thickness of sediments exposed in the area is in the vicinity of 30,000 ft., neither the base nor the top of the sequence has been found, and there seems no evidence that either was approached. Further, from the work of Raggatt (1934), Joplin (1952), Stevens (1950 and 1951) and Packham (in preparation), and from earlier work of the present writer, it is clear that these sediments form part of a sequence extending over some thousands of square miles of the Central Tablelands of New South Wales. In view of this great thickness and extent, and the nature of the sequence itself, its eugeosynclinal formation seems certain.

It is likely that folding of the sediments took place during the Bowning orogeny, and that it was accompanied by the emplacement of the Davies Creek Granite and the " porphyroids ". The composition of the Burraga Granodiorite, and its relationships with the adjacent sediments and the structures in which these are involved, suggest that the intrusion may be co-magmatic with the Bathurst-Hartley batholith, and hence that it is of Lower Carboniferous age.

In its later history (including post-Palæozoic erosion, Tertiary uplift and vulcanicity, and Pleistocene and Recent erosion) the Burraga-Wiseman's Creek area falls into the general pattern already established for the Central and Southern Tablelands of New South Wales.

CONCLUSION.

The foregoing general account of the geological features of the Wiseman's Creek-Burraga area has been given as an addition to the present knowledge of the Lower Palæozoic rocks of N.S.W. The mapping may be regarded as an eastward extension of that already done by Raggatt, Joplin, Stevens and others in the Peelwood-Cowra-Orange region, and is thus a further contribution to a geological map of the Central Tablelands.

The features of the sediments, and of their succession, indicate some interesting variations in conditions and tectonic enviroment of sedimentation and may have some bearing on present knowledge of the history of the Tasman Geosyncline. It has been thought best, however, to leave such considerations to a much broader palæo-geographical study.

ACKNOWLEDGEMENTS.

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STUDIES OF THE DIASTEREOISOMERIC EFFECT.

PART I. THE SOLUBILITIES OF (+) AND (−) TRIS-1 : 10-PHENANTHROLINE RUTHENIUM II PERCHLORATES IN SOLUTIONS CONTAINING OPTICALLY ACTIVE IONS.

By F. P. DWYER, D.Sc.,
E. C. GYARFAS, M.Sc., Ph.D.,
and M. F. O'DWYER, B.Sc.

In order to account for the movement of the equilibrium between the enantiomeric forms of a complex inorganic ion in solution in the presence of another optically stable ion—the so-called phenomenon of " first order asymmetric (Turner and Harris, 1948) transformation "—the concept of " con figurational activity " was put forward (Dwyer, Gyarfas and O'Dwyer, 1951). If a_d+ and a_l+ represent the equal activities of the labile dextro and laevo ions in the racemic mixture, then in the presence of another optical ion it was suggested that a_d+, a_l+ and the equilibrium moves until the activities are again equal. As a result, the concentrations of the antipodes become unequal with a consequent net dextro or laevo rotation. Since the solubilities of simple salts of optical forms are equal, it follows that in their saturated solutions $a_d+=a_l+$. The addition of an extraneous optically active ion, if it affects the activities differently, should consequently change the solubilities of the antipodal forms unequally if they are not labile.

Tris-1 : 10-phenanthroline ruthenium II perchlorate is a suitable optically active complex salt, since the optical forms are stable and have a solubility of only $1 \cdot 5 \times 10^{-3}$ M at 25° C. The (+) tartrates and (+) bromcamphorsulphonates are both very soluble in water. Suitable optically stable, colourless inorganic anions or organic cations were not available.

APPARATUS AND EXPERIMENTAL PROCEDURE.

Tris-1 : 10-phenanthroline ruthenium II perchlorate was resolved as described previously (Dwyer and Gyarfas, 1949). The active perchlorates were crystallized several times from hot water by the addition of sodium perchlorate and finally twice from distilled water. The optical forms crystallized well in small prisms of uniform size and had $[a]_D^{20} = \pm 1330°$. Ammonium (+) bromcamphorsulphonate was crystallized from water using decolourizing charcoal to remove a slight yellow tint, and dried at 100° C. Sodium potassium (+) tartrate tetrahydrate A.R. was used without purification. Solubilities were determined in the apparatus of Campbell (1930). However, adsorption of the ruthenium compound on the glass wool filter was found to lead to low or erratic results and ultimately a small sintered glass filter was substituted. Samples of the saturated solution, 3–4 mls., were usually taken after equilibration at 25° $\pm 0 \cdot 02°$ for 20–24 hours. The concentration of the ruthenium compound was determined with a Spekker Photoelectric Colorimeter using Ilford blue filter 603, and a calibration curve prepared from an aqueous solution of the (+) perchlorate. In the range $0 \cdot 025$ to $0 \cdot 05$ g./100 ml. the calibration curve was

almost a straight line, and the volumes of the various samples were arranged so that the centre of this straight line portion was used.

Since the difference in the solubilities of the (+) and (−) forms was frequently close to the experimental error, all operations were carefully standardized. In order to check for colour purity of the optical forms, a number of solutions of each were compared. No systematic difference was noted, the maximum variation being $\pm 0 \cdot 1 \%$.

It was found that addition of ammonium (+) bromcamphorsulphate to solutions of the ruthenium compound caused a shift in the absorption maximum towards the blue, leading to an apparent increase in concentration. In $0 \cdot 25 \%$ solution, the maximum concentration in the diluted solutions, this led to the same error of 2% for either optical form. From a second curve, all concentrations were corrected for this effect. Ammonium β-naphthalene sulphonate also caused a similar absorption shift but sodium chloride and sodium potassium (+) tartrate were without effect.

For comparison, the solubility of bis-$2 : 2' : 2''$-terpyridyl iron II perchlorate (Morgan and Burstall, 1930) was determined in ammonium (+) bromcamphorsulphonate. The cation of this deep purple salt carries the same charge as that of the ruthenium compound, is chemically analogous, of approximately the same size but is optically inactive. The concentration in the saturated solution was determined as before spectrophotometrically, using Ilford filter 605. An absorption shift was also noted with this compound in the presence of bromcamphorsulphonate ion.

EXPERIMENTAL RESULTS.

The solubilities* shown in Tables I and II are the mean of at least six determinations for which the maximum deviation from the value quoted was

TABLE I.

The Solubilities and Mean Activity Coefficients in Solutions of Ammonium (+) Bromcamphorsulphonate.

Concentration of $NH_4C_{10}H_{14}OBrSO_3$ Molarity $\times 10^{-2}$.	Solubility of (+) and (−) $Ru(phenan)_3(ClO_4)_2 \cdot 2H_2O$ Molarity $\times 10^{-3}$.	$I - I_0$.	$\log S/S_0$.	$f\pm$
0	(+) $1 \cdot 75_5$	0	0	$0 \cdot 941$
	(−) $1 \cdot 75_6$	0	0	$0 \cdot 941$
$0 \cdot 4$	(+) $1 \cdot 93_6$	$0 \cdot 0254_6$	$0 \cdot 0424$	$0 \cdot 852$
	(−) —	—	—	—
$0 \cdot 8$	(+) $2 \cdot 02_9$	$0 \cdot 0434_0$	$0 \cdot 0627$	$0 \cdot 813$
	(−) $2 \cdot 03_3$	$0 \cdot 0434_0$	$0 \cdot 0637$	$0 \cdot 812$
$1 \cdot 57$	(+) $2 \cdot 30_3$	$0 \cdot 0762_0$	$0 \cdot 117_8$	$0 \cdot 713$
	(−) $2 \cdot 31_5$	$0 \cdot 0763_0$	$0 \cdot 120_0$	$0 \cdot 714$
$3 \cdot 05$	(+) $2 \cdot 75_8$	$0 \cdot 124_2$	$0 \cdot 196_1$	$0 \cdot 599$
	(−) $2 \cdot 79_4$	$0 \cdot 124_5$	$0 \cdot 201_6$	$0 \cdot 591$
$4 \cdot 62$	(+) $3 \cdot 18_8$	$0 \cdot 162_5$	$0 \cdot 259_1$	$0 \cdot 518$
	(−) $3 \cdot 20_1$	$0 \cdot 162_6$	$0 \cdot 260_8$	$0 \cdot 516$
$6 \cdot 1$	(+) $3 \cdot 57_1$	$0 \cdot 195_0$	$0 \cdot 308_2$	$0 \cdot 462$
	(−) $3 \cdot 54_7$	$0 \cdot 194_9$	$0 \cdot 305_4$	$0 \cdot 466$

$\pm 0 \cdot 3 \%$. The mean activity coefficients were obtained in the usual way by extrapolating the solubility curve obtained with sodium chloride to $I = 0$ to obtain the solubilities of either form as $1 \cdot 65 \times 10^{-3}$ M.

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* The values quoted previously (Turner and Harris, 1948) were obtained in the original apparatus of Campbell. Owing to an error, the signs of the antipodes were reversed.

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TABLE II.

The Solubilities and Activity Coefficients in Solutions of Sodium Potassium (+) Tartrate.

Concentration of $NaKC_4H_4O_6-4H_2O$ Molarity $\times 10^{-2}$.	Solubility of (+) and (−) $Ru(phenan)_3(ClO_4)_2.2H_2O$ Molarity $\times 10^{-3}$.	$I-I_0$.	log S/S_0.	$f\pm$.
0·45	(+) 2·02$_2$	0·0666	0·0612	0·816
	(−) 2·03$_3$	0·0667	0·0637	0·811
0·9	(+) 2·12$_7$	0·109$_1$	0·0832	0·776
	(−) 2·18$_7$	0·109$_5$	0·0953	0·755
1·8	(+) 2·22$_9$	0·172$_1$	0·103$_5$	0·740
	(−) 2·29$_1$	0·172$_4$	0·115$_5$	0·720
3·6	(+) 2·39$_8$	0·264$_5$	0·135$_3$	0·688
	(−) 2·44$_3$	0·265$_1$	0·143$_4$	0·675
7·2	(+) 2·55$_4$	0·396$_7$	0·162$_6$	0·646
	(−) 2·61$_6$	0·397$_0$	0·173$_1$	0·631

The results are expressed in the form (Fig. 1) used by Bronsted and La Mer (1924) in their studies of the solubilities of cobaltammines.
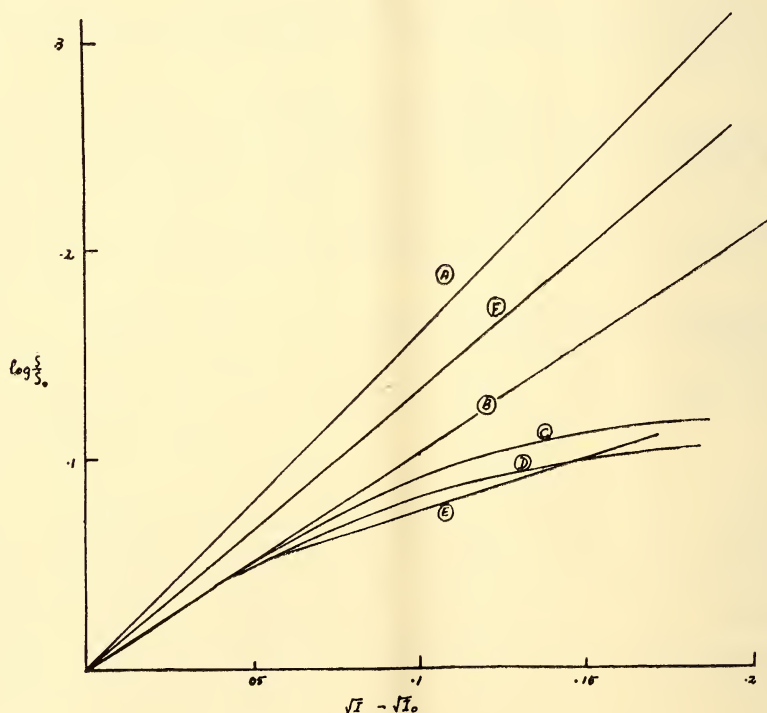
Text-fig. 1.

A. (+) $Ru(phenan)_3(ClO_4)_22H_2O$ in the presence of ammonium (+) bromcamphor-sulphonate.
B. Theoretical slope (calculated from Debye-Huckel limiting law).
C. (−) $Ru(phenan)_3(ClO_4)_22H_2O$ in the presence of sodium potassium (+) tartrate.
D. (+) $Ru(phenan)_3(ClO_4)_22H_2O$ in the presence of sodium potassium (+) tartrate.
E. (+) $Ru(phenan)_3(ClO_4)_22H_2O$ in the presence of sodium chloride.
F. $Fe(terpyridyl)_2(ClO_4)_2.H_2O$ in the presence of ammonium (+) bromcamphor-sulphonate.

From the expression

$$\log \ S/So = AZ + Z - (I^{\frac{1}{2}} - I_0^{\frac{1}{2}}) \quad \ldots \ldots \ldots \ldots \ldots \quad (1)$$

derived from the simple Debye-Huckel Law, it was shown that the plot of $\log \ S - So$ against $I - I_0$ was a straight line of slope $AZ + Z -$ (So and S are respectively the molar solubilities in pure water, where $I = I_0$, and at ionic strength I, $Z+$, $Z-$ are the ionic charges and $A = 0.51$). Since large ions are involved, the extended expression

$$\log \ S/So = AZ + Z - \left(\frac{I^{\frac{1}{2}}}{1 + \alpha B I^{\frac{1}{2}}}\right) - I_0^{\frac{1}{2}} \quad \ldots \ldots \ldots \quad (2)$$

(α is the average effective diameter of the ions, B is a constant) is the more appropriate except at very low ionic strengths—but its use would not affect the conclusions reached. In approximately 5×10^{-2} M solution of bromcamphorsulphonate the solubilities of the antipodes are equal ; above this concentration the (+) form is the more soluble. No explanation can be advanced at this stage for the reversal of the solubilities.

DISCUSSION OF RESULTS.

It is evident that the solubilities of the (+) and (−) forms are different in the presence of the optically active electrolytes, and the curves (Fig. 1) do not follow the theoretical slope for Bebye Huckel interionic forces. Although with the tartrate ion the limiting slope ($AZ + Z-$) applies at approximately the same ionic strength as with sodium chloride, the slope at higher ionic strengths is too large for a large ion. Even at the lowest ionic strengths the slopes of the curves of the ruthenium and iron compounds in the presence of bromcamphorsulphonate ion are too great. Since the bis-$2 : 2' : 2''$-terpyridyl iron compound is not optically active this cannot be ascribed to a special form of interaction due to the optical activity. It is probable that these large cations are " salted in " by the bromcamphorsulphonate ion and to a lesser extent by the tartrate ion. The possibility that the properties of large ions are not treated adequately by Debye-Huckel interionic forces but that Van der Waals forces—especially the dispersion interaction component—may be important, has already been envisaged by Kortum (1936), who has ascribed absorption maxima shifts in electrolytic solutions of the type noted with the ruthenium and iron compounds in the presence of bromcamphorsulphonate ion, to the operation of these forces. A quantitative treatment of the lyotropic " salting in " of non-electrolytes by large ions, based primarily upon dispersion interaction forces, has been made by Bockris, Bowler-Reed and Kitchener (1951), but such a treatment does not appear to be available for purely electrolytic systems.

Van der Waals dispersion interaction forces between an optically active substance and the antipodal forms of another would not be identical, but since these forces decrease very rapidly with separation of the interacting units, they could contribute little to antipodal differentiation in dilute solution. If appreciable differentiation can occur in dilute solution without association, the only other component of Van der Waals forces that is available is the interaction between particles with an asymmetric distribution of charge. It is believed that the existence of such asymmetric electric fields is fundamentally associated with the phenomenon of optical activity. These fields, which are mirror image with respect to the antipodes, may arise from the asymmetry of the centre itself as in carbon and related atoms due to the arrangement of four different dipoles (Betti, 1930) or from the asymmetric distribution of charge over the ligands (Pauling, 1948) in complex inorganic compounds. Organic compounds exhibiting

molecular asymmetry without an asymmetric carbon atom belong to the latter category.

The electrical asymmetry of the antipodes of complex inorganic compounds in which the asymmetry is centred in a multi-charged ion may be considerable and Van der Waals interaction even with the weak fields due to the four different dipoles in an organic molecule could lead to considerable differentiation.

SUMMARY.

Measurements on the perchlorates of a pair of optical antipodes have shown that the solubilities are appreciably different in the presence of optically active electrolytes. The nature of the forces responsible for such differentiation— the " diastereoisomeric effect "—is discussed.

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STUDIES OF THE DIASTEREOISOMERIC EFFECT.

PART II. THE REDOX POTENTIALS OF THE SYSTEMS (+) AND (−), TRIS-2 : 2'-DIPYRIDYL OSMIUM II/(+) AND (−), TRIS-2 : 2'-DIPYRIDYL OSMIUM III IN THE PRESENCE OF OPTICALLY ACTIVE ELECTROLYTES.

By G. T. BARNES, B.Sc.,
J. R. BACKHOUSE, M.Sc.,
F. P. DWYER, D.Sc.,
and E. C. GYARFAS, M.Sc., Ph.D.

The redox system tris-2 : 2'-dipyridyl osmium II/tris-2 : 2'-dipyridyl osmium III investigated recently (Barnes, Dwyer and Gyarfas, 1952) was found to be reversible, equilibrium being attained rapidly. The complex cations derived from strong bases have considerable chemical stability and do not undergo hydrolysis so that reproducible potentials could be obtained at low ionic strengths.

Since both oxidant and reductant ions exist in stable enantiomeric forms (Burstall, Dwyer and Gyarfas, 1950 ; Dwyer and Gyarfas, 1951), it is possible to construct the redox systems $(+)\text{Os(dipy)}_3^{++}/(+)\text{Os(dipy)}_3^{+++}$ and $(-)\text{Os(dipy)}_3^{++}/(-)\text{Os(dipy)}_3^{+++}$ in which the configurations of oxidant and reductant in each system are the same. The system $(+)\text{Os(dipy)}_3^{++}/(-)\text{Os(dipy)}_3^{+++}$ and its antipode, however, are optically unstable, rapid electron transfer leading to racemization (Dwyer and Gyarfas, 1949).

The $(+)/(+)$ and $(-)/(-)$ systems offer a means of determining whether the differential interaction of an optically active substance with the antipodes of another—the " diastereoisomeric effect " is simply a geometrical effect, due to the possibility of closer approach to one antipode than to the other, or whether optically active substances have an associated asymmetric electric field permitting van der Waals charge interaction at a distance. As well as having the same configuration, the large oxidant and reductant ions in each system are probably very similar in size, despite the charge difference. The octahedral covalent radii of Os^{II} and Os^{III} are also nearly identical (Pauling, 1939). As a result, an extraneous optically active ion should be capable of approaching the oxidant and reductant ions of each system equally closely, if the geometry of the interacting species alone is considered. Since the potential of a redox system is a function of the ratio of the activities of oxidant and reductant ions, it follows that the potentials of the $(+)/(+)$ and $(-)/(-)$ systems should be the same when any optically active electrolyte is used to raise the ionic strength if spatial considerations alone determine the " diastereoisomeric effect ". In any event, at low ionic strengths spatial considerations tend to become unimportant since the average distance of approach of the ions is large compared with their size. If, on the other hand, in conformity with the postulates advanced previously (Dwyer and Gyarfas, 1949), the ionic charges of oxidant and reductant contain an asymmetric component due to the nature of the charge

distribution, it might be expected that the slopes of the redox potential of the antipodal systems would be different in the asymmetric electrical field of another optically active ion.

The $(+)/(+)$ and $(-)/(-)$ systems also permit the confirmation of the identity of the redox potentials of antipodal compounds at the same ionic strength and should cast some light on the existence of the so-called " racemate compounds " in solutions. Previously (Dwyer and Gyarfas, 1949), it has been found with the unstable tris-2 : 2'-dipyridyl ruthenium II/tris-2 : 2': dipyridyl ruthenium III system that the potentials of the dextro, laevo and racemate systems were the same within ± 2 mV.
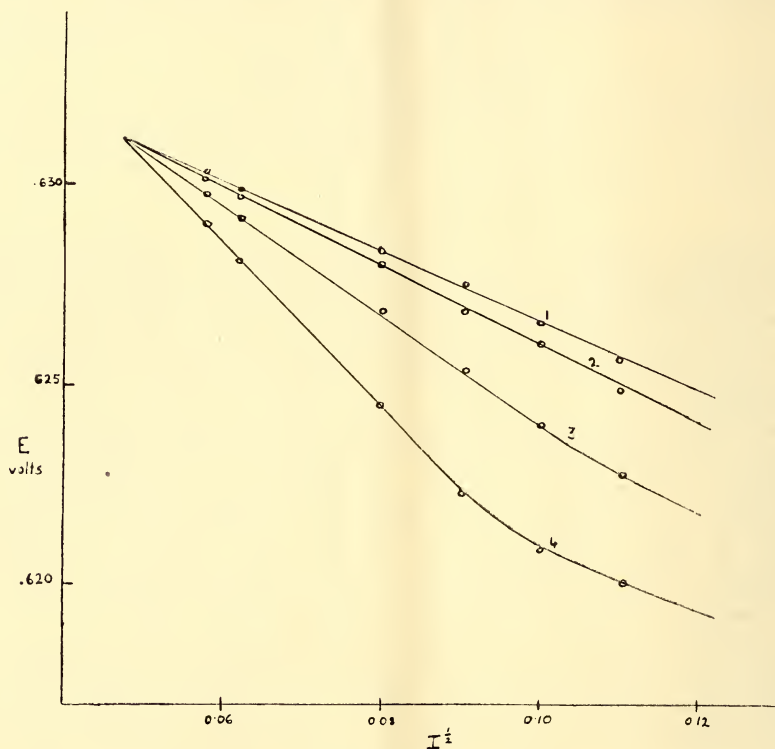
Text-fig. I.

1. $(+)$ Os(dipy)$_3^{++}$/$(+)$ Os(dipy)$_3^{+++}$ in the presence of ammonium $(+)$ brom-camphorsulphonate (slope, $8 \cdot 4$).*
2. $(-)$ Os(dipy)$_3^{++}$/$(-)$ Os(dipy)$_3^{+++}$ in the presence of ammonium $(+)$ brom-camphorsulphonate (slope, $9 \cdot 8$).
3. $(-)$ Os(dipy)$_3^{++}$/$(-)$ Os(dipy)$_3^{+++}$ in the presence of ammonium $(+)$ camphor-sulphonate (slope, $13 \cdot 6$).
4. $(+)$ Os(dipy)$_3^{++}$/$(+)$ Os(dipy)$_3^{+++}$ in the presence of ammonium $(+)$ camphor-sulphonate (slope, $20 \cdot 2$).
   * Mv./$0 \cdot 1 I^{\frac{1}{2}}$.

EXPERIMENTAL PROCEDURE.

Tris-2 : 2'-dipyridyl osmium II iodide was resolved as described previously (Burstall, Dwyer and Gyarfas, 1950) and the active iodides transformed to the perchlorates—Os(dipy)$_3$(ClO$_4$)$_2$.2H$_2$O gave $[\alpha]_{5461}^{20} = \pm 3300$. Oxidation of each antipode with chlorine in aqueous solution followed by precipitation with sodium

perchlorate gave the Os^{III} complex of the same configuration (Dwyer and Gyarfas, 1951), $Os(dipy)_3(ClO_4)_3.3H_2O$, $[\alpha]_{5461}^{20} = \pm 300°$. The stock solution, which was prepared frequently, was M/2000 with respect to oxidant and reductant, and subsequently diluted with the added electrolyte to M/4000. Ammonium (+) camphorsulphonate was prepared from A.R. (+)10-camphorsulphonic acid by neutralization with ammonia, evaporation to dryness and recrystallization. Ammonium (+) bromcamphorsulphonate was purified as described
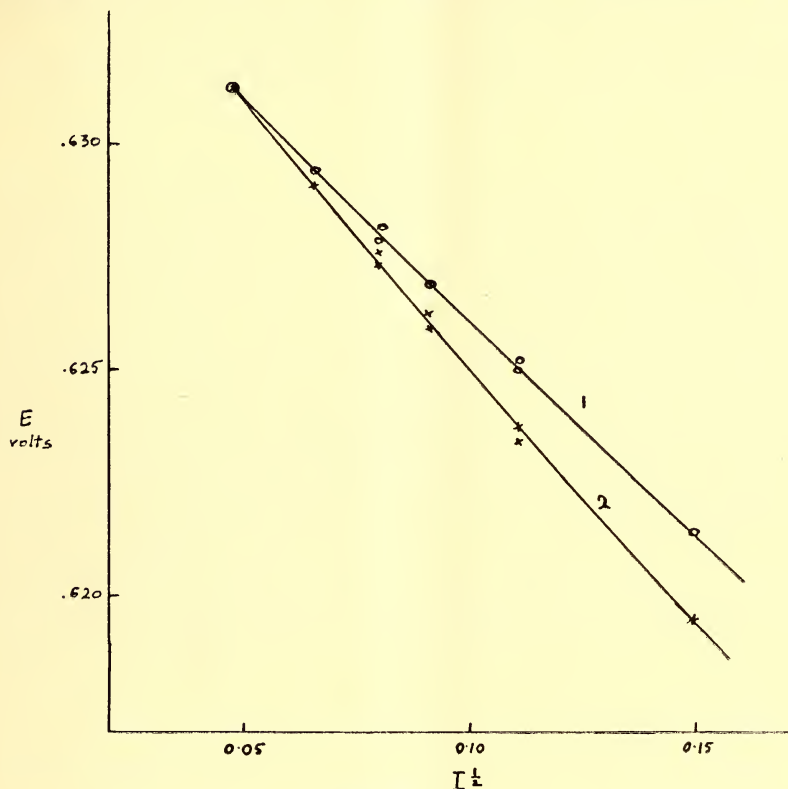
Text-fig. II.

1. The potentials of the $(+) Os(dipy)_3^{++}/(+) Os(dipy)_3^{+++}$ system in the presence of $(-) Co(ene)_3^{+++}$ and of the $(-) Os(dipy)_3^{++}/(-) Os(dipy)_3^{+++}$ system in the presence of $(+) Co(ene)_3^{+++}$ (slope, 10·8).*

2. The potentials of the $(+) Os(dipy)_3^{++}/(+) Os(dipy)_3^{+++}$ system in the presence of $(+) -Co(ene)_3^{+++}$ and of the $(-) Os(dipy)_3^{++}/(-) -Os(dipy)_3^{+++}$ system in the presence of $(-) Co(ene)_3^{+++}$ (slope, 9·8).

* $Mv./0·1I^{\frac{1}{2}}$.

previously (Dwyer, Gyarfas and O'Dwyer, 1955). Tris-ethylenediamine cobalt III iodide was resolved by the method of Werner (1912). The iodides, $[\alpha]_D^{20} = \pm 90°$, were transformed to the nitrates with excess silver nitrate and recrystallized.

For comparison of the effect of large optically active ions on an optically inactive system—bis-2 : 2' : 2"-terpyridyl osmium II and osmium III perchlorates (Morgan and Burstall, 1937) were used. The complex cations are very similar in size and chemical constitution to the dipyridyl complexes but are

optically inactive.   The redox mixture was M/2000 in 0·0001 N nitric acid.
The ratio of oxidant and reductant was found spectrophotometrically (Dwyer
and Gyarfas, 1951) after equilibrium had been reached, and the potentials
corrected to equimolarity.   This was necessary because of gradual reduction
of the oxidant ion.   The cell assembly and experimental technique were the
same as in the previous work (Barnes, Dwyer and Gyarfas, 1952).   It was
noticed that when electrodes, which had come to equilibrium in the $(+)/(+)$
mixture, were transferred to an identical $(-)/(-)$ mixture, the potential changed
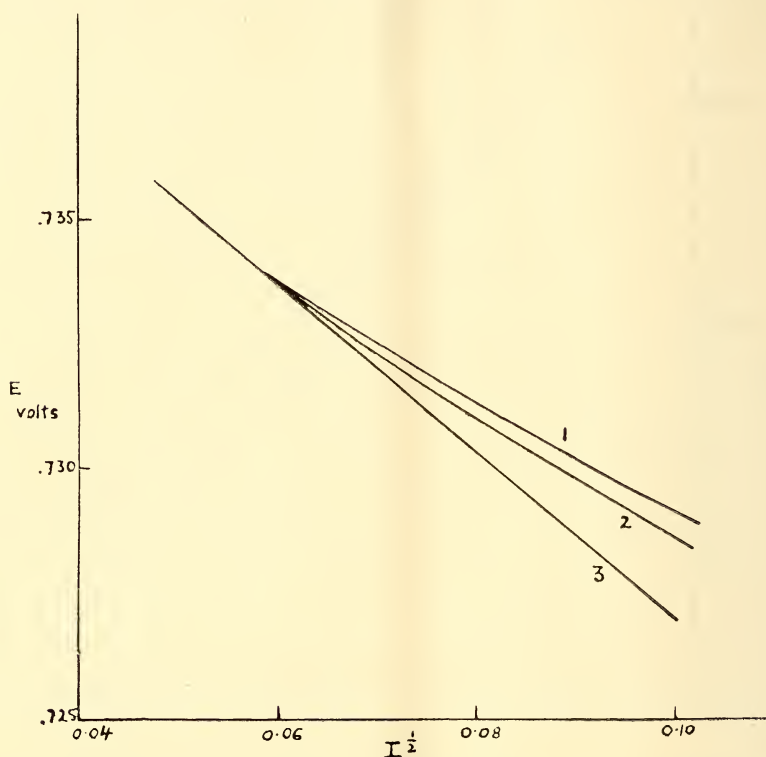
Text-fig. III.—The potential of the $Os(trpy)_2^{++}/Os(trpy)_2^{+++}$ system in the
presence of :

    1. ammonium $(+)$ camphorsulphonate.
    2. ammonium $(+)$ bromcamphorsulphonate.
    3. potassium nitrate.

immediately by 5–7 mV.   This value was constant for a few minutes, and the
potential then fell for 20–30 minutes to within 0·2 mV. of the original value.
In order to obviate uncertainty due to slow replacement of adsorbed ions on the
electrode surfaces, care was taken to allow sufficient time for equilibration
whenever the redox mixture was changed.

<center>RESULTS.</center>

The Potential of $(+)/(+)$, $(-)/(-)$ *and* $(\pm)/(\pm)$ *Cells.*—The potentials
were measured at $I=0·00225$, 25° C., the $(\pm)/(\pm)$ mixture was made by mixing
equal volumes of the antipodal mixtures.   The mean values of several deter-
minations were : $(+)/(+)$ and $(-)/(-)$, $E=+0·6314\pm0·2$ mV., $(\pm)/(\pm)$,

$E = +0 \cdot 6315 \pm 0 \cdot 2$ mV. All potentials within experimental error are therefore the same, $E_H = +0 \cdot 8737$ V.

The Effect of Optically Active Electrolytes on the Potentials.—The results are summarized in Figures I and II. In Figure III is shown the effect of various salts on the potential of the $Os(trpy)_2^{++}/Os(tryp)_2^{+++}$ system. The slopes obtained by extrapolation from about $I^{\frac{1}{2}} = 0 \cdot 1$ are approximate since the curves are not straight lines. For reasons advanced previously (Barnes, Dwyer and Gyarfas, 1952), the potentials of the pure redox mixtures varied a little. The maximum deviation was of the order of $\pm 0 \cdot 8$ mV. and for convenience the potentials at the commencement of each series have been corrected to the mean value, $+0 \cdot 6312$ V. against the saturated calomel electrode, $E = 0 \cdot 2422$ V. at 25° C.

DISCUSSION.

The potential curves show that optically active anions and cations can distinguish between antipodal redox systems even at fairly low ionic strengths and thus provide substantial support for the view that the " diastereoisomeric effect " arises from the interaction of asymmetric electric fields. Most significant are the results obtained in the presence of $(+)$ and $(-)$ tris-ethylenediamine cobalt III ion, for here the interactions are between multi-charged cations. Whilst the differentiation is small, the results clearly fall so closely into two sets involving the same relative configurations of the osmium compound and the cobalt complex that the four potential series can be plotted on two curves (Fig. II). The considerable differentiation shown by camphorsulphonate ion compared with the small effect with bromcamphorsulphonate ion can be ascribed to the differences in the electrical asymmetry of the ions, but it is probable that other factors such as the position of the sulphonic acid group with respect to the optical centre are also important.

In a redox system involving large ions, provided that the ionic strength is not too high ($I < 0 \cdot 3$), if the concentrations of the oxidant and reductant ions are equal, the potential can be expressed :

$$E = E_0 + 0 \cdot 0591 \log \frac{f_1}{f_2} = E_0 + 0 \cdot 0591 + 0 \cdot 505(Z_1^2 - Z_2^2)\frac{I^{\frac{1}{2}}}{1 + \alpha B I^{\frac{1}{2}}} \quad \cdots \quad (1)$$

where E is the potential at ionic strength I, E_0 is the standard redox potential $I = 0$, Z_1 and Z_2 are respectively the ionic charges of oxidant and reductant, α is the average effective diameter of the ions in the solution, and B is a constant.

Substituting in (1), $Z_1 = 3$, $Z_2 = 2$, $B = 3 \cdot 3 \times 10^7$:

$$E = E_0 + \frac{0 \cdot 148 I^{\frac{1}{2}}}{1 + 3 \cdot 3 \times 10^7 \alpha I^{\frac{1}{2}}} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

The plot of E against $I^{\frac{1}{2}}$ for various values of α is shown in Figure IV. At low ionic strengths the curves are approximately straight lines from which values of the slope for $0 \cdot 1$ unit of $I^{\frac{1}{2}}$ can be obtained. Similar calculations from the simple Debye-Huckel expression, in which the ionic sizes are ignored, give the slope as $14 \cdot 8$ mV./$0 \cdot 1 I^{\frac{1}{2}}$.

From the unstable (Dwyer and Gyarfas, 1951) $Os(tryp)_2^{+++}/Os(tryp)_2^{++}$ system in the presence of camphorsulphonate and bromcamphorsulphonate ions, the slope of approximately 12 gives the average effective diameter of the ions as about 10 A.U. This value, which is not easily calculated owing to the mixed ionic species present, and uncertainty of the extent of the hydration,

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can also be assigned to the optically active systems since the Os(tryp)$_2$ anf Os(dipy)$_3$ ions are approximately the same size.

The small slopes in the presence of bromcamphorsulphonate ion would require an ionic diameter of over 20 A.U., whilst the large slope of the $+/+$ system in the presence of camphorsulphonate ion is greater than that calculated from the simple Debye-Huckel Law.

Small slopes have been noted previously (Barnes, Dwyer and Gyarfas, 1952) with the racemate system in the presence of multi-charged cations such as La^{3+} and Th^{4+}. The explanation then advanced probably also applies largely to the small slopes observed in the presence of the tris-ethylenediamine cobalt III ion.
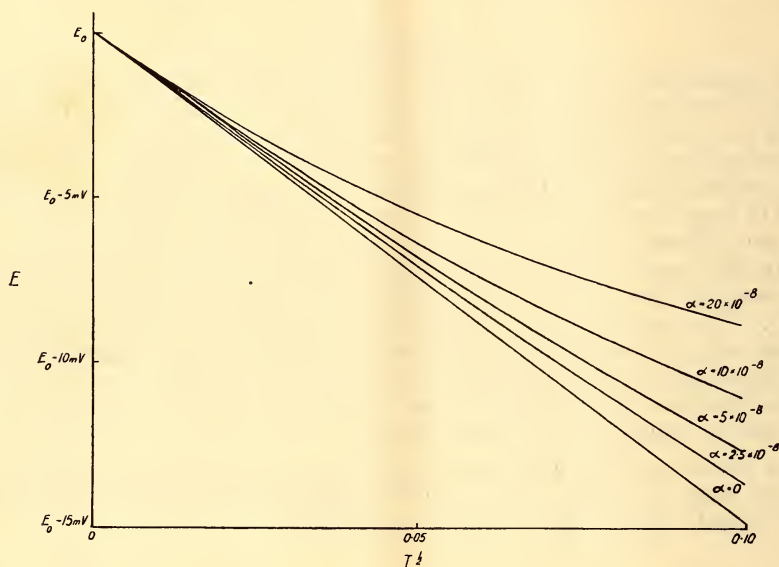
Text-fig. IV.

SUMMARY.

The potentials of two antipodal redox systems have been examined in the presence of optically active anions and cations. The potential curves show appreciable differences between the systems, and support the view that the diastereoisomeric effect may arise in solution by the interaction of the asymmetric electric fields of the antipodal ions and the added optically active substance.

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FOR

1955

(INCORPORATED 1881)

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F. N. HANLON, B.Sc., Dip.Ed.

Honorary Editorial Secretary

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THE THERMAL METAMORPHISM OF PORTIONS OF THE WOOLOMIN GROUP IN THE ARMIDALE DISTRICT, N.S.W.

PART II. THE TILBUSTER AND DUMARESQ AREAS.

By ALAN SPRY, M.SC.

Department of Geology, University of Tasmania.
(Communicated by S. WARREN CAREY.)

With Plate IV, and three Text-figures.

ABSTRACT.

Eugeosynclinal sediments of the Woolomin Group were intruded by a large Permian monzonite body. The interbedded lavas have been thermally metamorphosed to hornfelses rich in hornblende, diopside, grossular, plagioclase and sphene. The higher grade hornfelses show considerable lime metasomatism while some others have suffered intense scapolitization. Metasomatism by chlorine, iron, boron, soda and lime resulted in the formation of scapolite, magnetite, sodic tourmaline, plagioclase and diopside. Minor intrusions of Epi-Silurian (?) dolerite and pyroxenite have been metamorphosed. Some basic hornfelses are polymetamorphic and show the effects of thermal metamorphism superimposed on dynamic metamorphism. The associated greywackes, quartzites and jasper show alteration to a lesser extent.

INTRODUCTION.

A general summary of the regional geology of the area has been given by the author in a paper (Spry 1953) dealing with related rocks at Puddledock which is about eight miles east of Tilbuster and about twelve miles north-east of Dumaresq. The rocks at Tilbuster were first examined by Mr. Harrison of the New South Wales Geological Survey and both occurrences were mapped as part of the regional problem by M. Slade* in 1951.

THE TILBUSTER AREA.

The Lower Palæozoic Woolomin Group in this locality contains greywackes, siltstones, cherty quartzite, jasper and basic lava and was intruded during the Permian by a large monzonite body with small satellitic porphyry and alaskite plugs. There are four small dolerite bodies whose age relations are indefinite but which are probably genetically related to the basic flow.

The Permian Igneous Rocks.

The main igneous body consists of monzonite and extends for several miles to the south with its long direction approximately east-west. It is a coarse-grained rock, light in colour, with abundant feldspar phenocrysts many of which are over an inch across. It has a hypidiomorphic granular texture and consists chiefly of plagioclase and orthoclase in varying proportions accompanied by biotite, hornblende and quartz. The plagioclase occurs as

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* Unpublished thesis.

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subhedral crystals with twinning on combinations of the Albite, Carlsbad and Pericline laws and shows both compositional and alteration zoning. The average composition is andesine Ab_{65}. The orthoclase is strongly perthitic and forms anhedral crystals frequently enveloping the plagioclase to give a monzonitic fabric. The relative proportions of the two feldspars are variable and the rock grades from monzonite to diorite. The ferromagnesian minerals are biotite and pale green hornblende which frequently show intimate intergrowths. Quartz is not abundant and accessories are sphene, apatite, zircon and magnetite.

Quite near to this monzonite, but intruding the basic hornfels, are three sub-circular intrusions of porphyry. These outcrop very poorly and their size and intrusive relations are obscure. The largest may be about 100 feet across. One of these porphyries is almost identical with the main monzonite (apart from a finer grain) but specimens of the others are strikingly different. These are rather reddish rocks with abundant phenocrysts of feldspar and biotite the former being up to 4 cms., but usually less than 1 cm. in length. The texture is allotriomorphic as all crystals except the plagioclase show irregularly angular shapes. Many crystals show fracturing and alteration. The plagioclase is generally twinned on combinations of the Albite and Carlsbad laws and frequently shows a fresh untwinned peripheral zone with a highly sericitized core. Perthitic orthoclase is strongly kaolinised. The ferromagnesian minerals are reddish-brown biotite and actinolite with the latter forming fibrous masses as pseudomorphs after hornblende. Quartz and apatite are quite abundant with lesser sphene. The peculiar texture and alteration suggest that these porphyries were intruded as an almost solid " mush " of crystals which suffered protoclasis and that they formed channels along which hydrothermal fluids (chiefly water) passed from the mozonite into the basic hornfels.

There is a very small outcrop of alaskite immediately adjacent to the main igneous contact. It is a medium grained, leucocratic rock consisting of approximately equal amounts of perthitic orthoclase and quartz with a little albite. The feldspar is altered in part to a white mica with a birefringence lower than that of sericite. The quartz shows striking granophyric intergrowths with the orthoclase and has replaced it to a considerable extent. The space relations of this body as shown on the map suggest strongly that it resulted from the feldspathization of the quartzite. The outcrop was not sufficiently continuous however to find any gradation, and if this genesis is correct, one would expect to find some evidence of the replacement of quartz by feldspar in thin section but the texture seems to indicate the contrary.

The Metamorphic Rocks.

The hornfelses which are in contact with the monzonite show thermal alteration to varying degrees. Few of the rocks have reached a condition of equilibrium with their environment and it appears that there may have been a lack of time or intergranular fluid in the hornfelses as the mineralogical changes in response to the elevated temperature were very sluggish. The basic lava shows the most obvious alteration and this is due to its susceptible mineralogical assemblage with the presence of calcite. Even in these hornfelses there is only a vague degree of regularity and most specimens show suspended mineralogical changes. It is a noticeable feature that many rocks close to the monzonite are much less altered than those found half a mile from the contact.

Sedimentary Hornfelses.

The sediments which occur in this area are typical of the Woolomin Group as a whole and are altered in various degrees. Greywackes (as defined by Pettijohn, 1949) are most common and include rocks ranging in grain size from breccias to siltstones. These rocks originally consisted of angular particles of

quartz and feldspar with various rock fragments and varying amounts of fine argillaceous matrix. Feldspar occurs both as fresh and weathered fragments and the most common composition is andesine. The rock fragments include graphic and myrmekitic quartz-feldspar intergrowths, spilite, chert, quartzite, slate and greywacke. Those containing abundant basic lava fragments are possibly tuffaceous. Practically all specimens in this area show at least some alteration of the matrix although one showed only a slight development of chlorite. The majority show considerable or complete recrystallization of the matrix to a fine-grained aggregate rich in biotite and pale hornblende. A few specimens show recrystallization of the larger clastic fragments also, and the best example was found near the northern extremity of the lava, well away from the monzonite. Allogenic apatite, zircon and rare epidote remained unaltered but ilmenite which is common usually gave rise to sphene. There is no relation between the degree of alteration of the sediments and either grain size or distance from the monzonite.

It was observed that the greywackes which are immediately adjacent to the basic hornfels often contain disseminated pyrite and veins carrying albite, albite plus tourmaline or albite plus scapolite. This material may have come from the monzonite by passing along the lava band and then spreading out for a short distance into the surrounding greywackes. On the other hand it may have been originally present in the lava itself and was driven out during metamorphism.

Along the southern part of the western margin of the basic hornfels there is a narrow, irregular series of outcrops of very fine-grained, grey, cherty quartzite. This kind of rock occurs frequently in the Woolomin Group and is typified by the presence of isoclinal folds which vary in size from several metres across to microscopic dimensions. Its genesis is not known but it may have been deposited as a silica gel which suffered slumping prior to lithification. The rock now consists of quartz grains averaging $0 \cdot 01$ mm. diameter and shows a granoblastic texture. There are some porphyroblasts of quite shapeless and cloudy albite but the chief metamorphic effect has been the production of tiny disseminated biotite laths about $0 \cdot 05$ mm. long. A little granular apatite and sphene are usually present while some specimens are cut by veins containing quartz, albite, or albite plus blue tourmaline.

One of the most striking rocks in the area occurs as a small outcrop lying within the basic hornfels just up the hill from the monzonite contact. It is a saccharoidal rock of rusty red colour with a rather friable nature due to weathering. The grainsize is generally fine but is most irregular and the rock shows patches of coarsely crystallized quartz. The texture is crystalloblastic with crystals of quartz varying from $0 \cdot 05$ mm. to 2 mm. in diameter. The quartz crystals (particularly the smaller ones) tend to develop a crystal form and some which are easily extracted from the crumbly rock show hexagonal prism and pyramid faces. There is a great deal of magnetite present and this frequently appears as bunches of perfect octahedra. A yellow oxidation and hydration product is visible in thin sections and this stains the quartz, particularly along intergranular boundaries.

The exceptional mineralogical composition of this rock suggests that it has been formed by thermal matamorphism of the jasper which is common in this area. These jaspers are red-coloured massive rocks consisting of cryptocrystalline quartz and hæmatite. Large masses are found among the greywackes and spilites of the Woolomin Group where they have been formed by silicification and replacement of those rocks. This silicification is a regional process related to the mid-Palæozoic folding of the Woolomin Group and the elongation of the masses shows a strong control by the structure of the replaced rocks. Slade (personal communication) considered that the jaspers were formed

prior to the emplacement of the Permian granites and this occurrence of thermally metamorphosed jasper confirms his finding. The jasper assemblage of quartz and hæmatite has been altered to quartz and magnetite without any tendency to form iron silicates. It is possible that the amount of iron present has been supplemented by metasomatic additions in the same way as the magnetite masses described later were introduced into the basic hornfels.
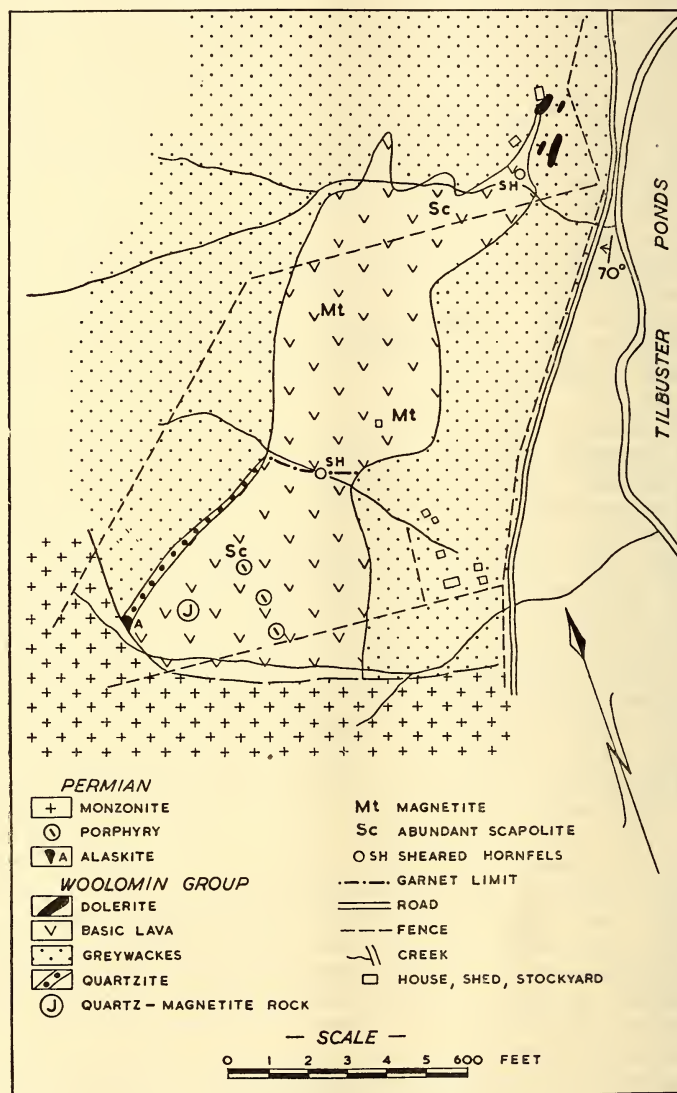
Text-fig. 1.—Geological Map of the Tilbuster Area.

Basic Hornfelses.

The two varieties of basic igneous rock which have been thermally metamorphosed are an interbedded flow and a group of small intrusions. The basic lava is very approximately 300 feet thick and may possibly contain a number of amygdaloidal and massive flows although these could not be

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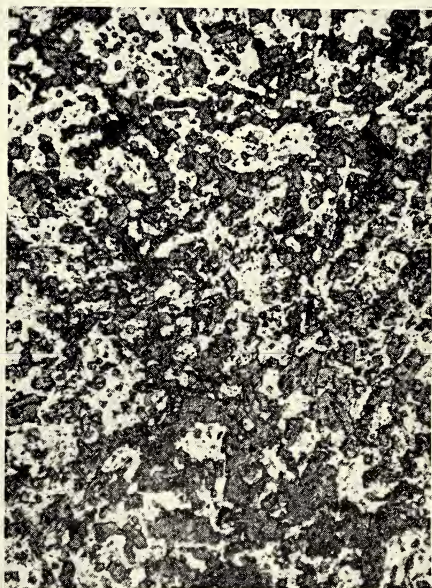
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satisfactorily delineated in their metamorphosed condition. The lava ends very abruptly along the strike against greywackes rich in lava fragments and does not show a gradual thinning. The explanation of this probably lies in the fact that during folding, the flow was very incompetent compared with the surrounding greywacke and was considerably deformed thus losing its original shape and taking on the irregular form shown in Fig. 1.

The nature of those basic lavas remote from the granitic intrusions (e.g. near the University) indicates that some are spilitic although the metamorphic mineral assemblages do not indicate such an abundance of soda as to produce sodic pyroxene or amphibole. Analysis 1 in Table 1 shows $6 \cdot 86\%$ of soda and $0 \cdot 77\%$ of potash and is thus spilitic while analysis 2 shows only $2 \cdot 60\%$ of soda and $0 \cdot 20\%$ of potash, thus resembling a normal basalt. It is of course not clear whether the high soda in No. 1 is due to metasomatism during thermal metamorphism or whether it was present prior to the intrusion of the monzonite. Some specimens still contain primary labradorite and augite and show that there were normal basalts associated with the spilites.

The lavas here have been altered to hornblendic and diopsidic hornfelses in which grossular and scapolite sometimes figure prominently and which are typified by possessing relict igneous textures. Despite the ample collecting and sectioning of rocks from the area, only a slight relation could be found between the degree of metamorphism and the distance from the igneous contact. Only the hornfels nearest to the granite contains grossular and in Fig. 1 is shown the " garnet limit ", north of which garnet was not found. It should however be noted that only the basic hornfels most remote from the monzonite shows strong scapolitization or tourmalinization while only the hornfels very close to the contact contains unaltered primary labradorite and augite. It was noted, however, that there is a strong connection between the grade of metamorphism and the degree of lime metasomatism, as shown in Fig. 3.

Next to the contact are dark-greenish rocks containing abundant calcite-filled amygdales and a few phenocrysts of augite. The texture is chiefly inter-granular with primary plagioclase as laths up to 5 mm. long accompanied by some phenocrysts of augite and secondary hornblende. The plagioclase (labradorite Ab_{40}) is fairly fresh and shows twinning on combinations of the Albite, Carlsbad and Pericline laws. It has been altered in part to a sodic scapolite (approximately Ma_{65}) which has replaced it along cracks and cleavages or by an anastomosing network of veins. The scapolite itself is altered in places to an interlocking mesh of plates and fibres of a chlorite which is possibly clinochlore. This retrograde alteration usually involves hornblende and grossular as well as scapolite and may be represented thus :

$$\text{Scapolite} + \text{hornblende} + \text{grossular} \rightarrow \text{chlorite} + \text{calcite etc.}$$

The pyroxene phenocrysts are up to 7 mm. across and are a pale green augite (2V+ from 45° to 55°). It has usually been at least partially replaced by the brown hornblende which is abundant in most specimens. Amygdales are common and usually contain calcite with a rim of grossular. The fillings also include plagioclase (albite, andesine, and labradorite) or prehnite. One amygdale contains hornblende, andesine and diopside with the amphibole and feldspar intergrown in a manner strongly resembling the ophitic texture of many dolerites (as shown in Plate 1, Fig. 3). This texture is metamorphic and not relict from any igneous texture because both minerals are metamorphic and they occur within an amygdale where ophitic texture would not be found in an igneous rock. The grossular rimmed amygdales are so closely set in one specimen that the hornfels consists chiefly of garnet and leucoxene with rounded patches of calcite. Diopside and fresh andesine are abundant in some specimens and primary pyroxene is replaced by garnet in one example. Ilmenite is

usually surrounded by a neat corona of sphene granules (as shown in Plate 1, Fig. 1) and sphene is rather common throughout the rock. Biotite occurs in large quantities in a few specimens which probably contained more potash and less lime than usual although the potash may have been metasomatic.

The most typical hornfelses are those in the northern half of the body and these resemble those previously described as group A rocks from Puddledock except that grossular is absent. They show blasto-intergranular texture, with albite plus hornblende in the less altered varieties and diopside plus a more calcic plagioclase in the more metamorphosed hornfelses which have a granoblastic texture. The amygdales are filled with calcite, quartz, plagioclase hornblende or scapolite. Sphene is usually abundant and chlorite occurs sporadically. In Table I are shown the chemical analyses of a series of basic hornfelses from Tilbuster and Puddledock showing a continuous range in the degree of metamorphism. Specimen 6733* is only slightly altered and shows a relict basaltic texture, consisting almost entirely of hornblende and albite with a little quartz occurring as occasional veins. No. 6732 is similar except that the feldspar is original dusty labradorite (Ab_{48}). Specimen 6734 is an amygdaloidal rock with amygdales rimmed with grossular set in a groundmass of rather fine grained diopside, andesine, grossular and minor sphene with vestigial intergranular texture. No. 6735 is quite similar and is one of the typical light-grey coloured blasto-amygdaloidal hornfelses rich in diopside and grossular. It differs chiefly from 6734 in containing some calcite. Specimens 6734 and 6735 are similar to the group A hornfelses from Puddledock (Spry, 1953), and an analysis is given of No. 6736 from that locality for comparison. The rock is amygdaloidal and contains partly intergranular hornblende and plagioclase and partly granular diopside and andesine with grossular and a little scapolite. No. 6987 from Puddledock is a representative of the group B hornfelses which are the most strongly altered and which contain wollastonite, calcite, diopside-hedenbergite and grossular. The analyses clearly show the lime metasomatism accompanying the thermal metamorphism and this is discussed in more detail in the final part of this paper.

In the south-western part of the basic hornfels, in the position indicated on the map, there is a dense, black hornfels with an encrustation of white scapolite in the joints. Here the scapolite, Ma_{55} ($N_E = 1 \cdot 547$, $N_o = 1 \cdot 568$, $D.R. = 0 \cdot 021$) has replaced andesine, Ab_{60}. To the north the scapolite is rather more sodic even when in contact with calcite.

The basic hornfelses in the northern part of the body are most remote from the igneous intrusion, but show particularly strong scapolitization. The scapolite entered along joints or cracks and formed veins across the rock. It then spread laterally and replaced the plagioclase laths over large areas, thus forming a mass of rather coarse xenoblastic crystals poikiloblastically enclosing diopside granules which often still outline the original intergranular texture. Further recrystallization resulted in a rather coarse scapolite-diopside aggregate (as shown in Plate 1, Fig. 4). Some rocks from here contain blue tourmaline, biotite, and amygdales filled with quartz.

A peculiar variety of hornfels was found at the localities indicated on the map by the symbol S.H., with the best examples in the southern exposure. This is a light coloured, strongly banded rock with lenticular amygdales. A thin section shows a rock with relict intergranular texture which has been broken up, first by streaky (almost schistose) bands and secondly by an irregular network of coarse recrystallised areas containing diopside, garnet, plagioclase and sphene. The amygdales contain calcite and grossular with a little plagioclase

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* Numbers refer to specimens in the collection of the Geology Department, University of Tasmania.

and are frequently elongated. The schistose portions are dark coloured and are almost opaque and isotropic but appear to consist of a very finely divided aggregate of hornblende, diopside and garnet with a great deal of leucoxene. The banded varieties from the northern parts show this structure to a much smaller degree and contain blue tourmaline in addition. There are two possible explanations of this textural peculiarity. The banding may be due to shearing or may mark flow layers in the lava. The flow layers in a semi-glassy rock might take on this appearance after devitrification and thermal metamorphism. From such evidence as bent feldspar laths and augen-shaped amygdales it is considered that the banding was caused by shearing along localized zones with the consequent production of bands of finely divided material prior to thermal metamorphism.

Magnetite occurs as masses up to several pounds in weight scattered over the surface and is abundant in the localities marked on the map. The mineral is often strongly polar and shows portions of octahedron faces but has the brown streak typical of hæmatite. A polished section shows that about half the magnetite has been altered to hæmatite by peripheral replacement yielding relict cores of magnetite surrounded by relatively broad areas of very fine grained hæmatite. Hornblende occurs abundantly in veins and patches. Observations with a magnetometer indicate that the mineral occurs as an irregular dissemination of small fragments and is not concentrated in a large deposit. This magnetite is presumed to have been introduced by the monzonite and its association with the chlorine-bearing scapolite suggests that the iron may have entered as volatile ferric chloride.

Dolerite occurs as three sills and an irregular mass immediately next to the northern end of the spilite about 1400 feet from the monzonite contact. It is a dark coloured, medium grained rock with ophitic to intergranular texture. It consists of large dusty albite laths up to 5 mm. long showing irregular twinning, together with a pyroxene (augite, $2V = 54°$) which has been almost entirely replaced by pseudomorphs of ragged brown hornblende. The effects of thermal metamorphism are slight as the saussuritization and uralitization are considered to be chiefly pre-monzonite as in the case of the basic flows. There has been a partial recrystallization to a granoblastic aggregate of plagioclase and diopside. The amphibole and plagioclase are both partially replaced by large radiating masses of tourmaline which is pleochroic from palest brown to deep blue. The fibrous hornblende has been altered to a well crystallized variety and the ilmenite is rimmed with sphene. A little chlorite and calcite occurs in some specimens.

The Dumaresq Area.

Thermally metamorphosed basic lava occurs in a small area on Dumaresq Creek several miles north-west of Armidale (Fig. 2). Several small plugs of dolerite and pyroxenite which intrude the lava have been thermally metamorphosed by the adjacent Permian batholith. The sediments are Woolomin Group greywackes, cherty quartzite and jasper.

Sedimentary Hornfelses.

The sediments are chiefly greywackes containing large clastic fragments of quartz, feldspar, and various rock types in a fine grained argillaceous matrix which is usually partially or wholly recrystallized to biotite, hornblende and sphene. Some rocks show further alteration with recrystallization of the larger clastic fragments. Lack of equilibrium is shown by the occurrence in the same rock of biotite, brown hornblende, pale green actinolite, anthophyllite (?), zoisite, chlorite, prehnite and plagioclase.

There are fine-grained, dark coloured quartzites veined with quartz in the south-west of this area and these are often quite difficult to distinguish from the basic hornfelses in the field.

A small outcrop of red, saccharoidal, metamorphosed jasper occurs in the upper central part of the area and this is similar to the rock described above from Tilbuster.

Basic Hornfelses.

The rocks present originally consisted of basic lava, sheared lava, dolerite and pyroxenite, all of which have been thermally metamorphosed.

The lava was originally a massive, porphyritic basalt with many large phenocrysts of augite and plagioclase up to 5 mm. across and a few calcite
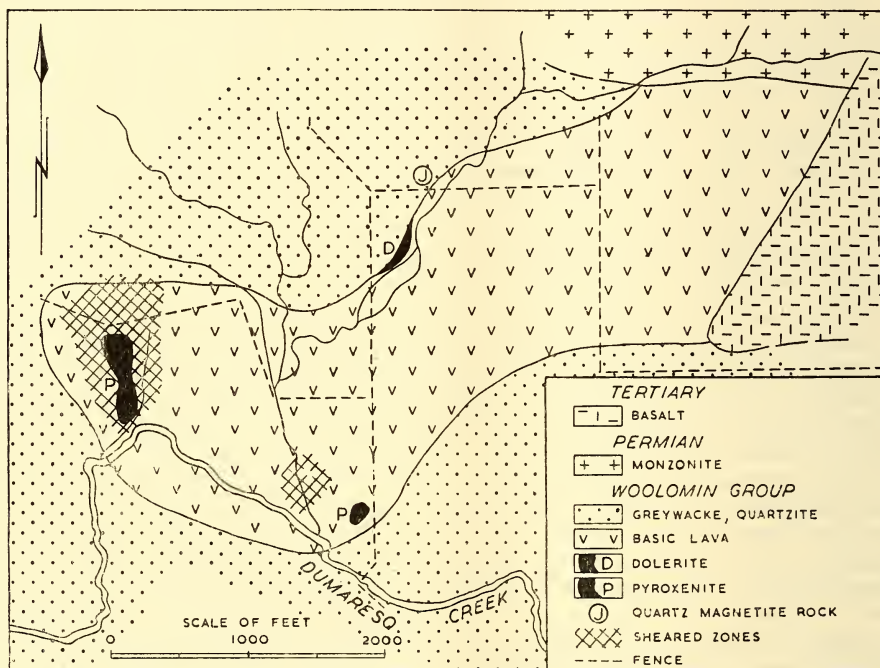
Text-fig. 2.—Geological Map of the Dumaresq Area.

filled amygdales. The augite ($2V=45°$) has been partially or wholly pseudomorphed by ragged brown hornblende which is also the chief constituent of the groundmass where it shows a blasto-intergranular texture with either albite or original labradorite (Ab_{40}). Original plagioclase forms laths which are usually dusty or clouded with inclusions of sericite or actinolite and occasionally show irregular twinning on the Albite and Carlsbad laws. The metamorphic plagioclase is fresh, shapeless and mostly untwinned. It is common to find large dusty phenocrysts of albite partially or wholly replaced by a fine granular aggregate of fresh andesine (Ab_{65}) crystals. In a few specimens there are veins or irregular patches of granoblastic diopside and andesine. Pyrite is distributed sporadically in small grains.

Many of these rocks are sheared and this is attributed to the Epi-Silurian (?) orogeny which was considerably earlier than the thermal metamorphism associated with the Permian batholith. The irregular shape and discontinuity

of the lava suggests that it was squeezed and deformed as an incompetent body during the folding. This deformation has resulted in a sheared appearance of some of the basic hornfelses, particularly those in the western extremity where the body has been " pinched out ".

The sheared hornfelses are mostly similar to those described above from Tilbuster. The plagioclase laths are bent or broken and some show an irregular secondary twinning. Both plagioclase and pyroxene phenocrysts become drawn out into augen forms and are replaced by new feldspar and fibrous hornblende respectively. The amygdales are strongly elongated and there has been much recrystallization due to thermal metamorphism with the formation of fresh untwinned plagioclase, hornblende, diopside, calcite and grossular. Grossular is absent from practically all rocks because of the lack of calcite filled amygdales which control its formation, however, it occurs in veins and amygdales in the rocks at the extreme north-western tip of the body. Narrow veins of diopside or hornblende are commonly found traversing the rocks. The rock appears massive in the hand specimen, but a thin section shows a platy, almost schistose mass of fine amphibole and feldspar which is practically impossible to resolve. One hornfels has been brecciated, giving a rock consisting of sub-rounded fragments which have later been partly recrystallized and blended together.

These rocks are good examples of polymetamorphics as the effects of thermal metamorphism have been superimposed on those of dynamic metamorphism. The general schistosity, augen shaped amygdales, parallel amphibole crystals and bent feldspar laths which are due to shearing have been partially obliterated by the growth of new minerals and the production of a granoblastic texture during contact metamorphism.

There are three small bodies of coarser-grained basic rock which apparently intrude the lava and these are indicated on Fig. 2.

One is a narrow body of dolerite on the margin of the flow and is a medium grained rock with intergranular to ophitic texture. The plagioclase is original labradorite Ab_{50} and forms laths up to $1 \cdot 5$ mm. long. These are frequently bent and show irregular twinning. The original pyroxene has been completely replaced by pseudomorphs of ragged pale brown hornblende, and amphibole also forms veins cutting the rock. A little iron ore is present.

The other two bodies consist of amphibolite which has been formed from pyroxenite. The sub-circular mass of about 100 feet diameter in the south-eastern part of the lava flow is a medium grained rock consisting chiefly of ragged amphibole crystals as pseudomorphs after a pale green pyroxene $(2V = 55°)$ which were up to 2 mm. in diameter but which now merely remain as small relics. The amphibole is very fibrous with Z = pale brown, Y = pale yellow and X = colourless, and is apparently actinolite. There was a very small amount of plagioclase which has been completely altered to muscovite.

The other amphibolite which occurs at the western extremity is a dark greenish-grey rock with a sheared appearance. The thin section reveals a very irregular, sheared texture with completely shapeless crystals. It consists almost entirely of pale actinolite with kernels of pale augite. A little sphene and muscovite are present.

The pyroxenites appear to have been the variety diopsidite and may have belonged to the tectonic group of ultrabasic rocks although it is perhaps more likely that these intrusions consisted of pyroxene accumulations formed from the basaltic magma by gravity differentiation. The pyroxene is very similar to that in the lavas and dolerites.

The area North of New England University.

It is difficult to find any basic lavas in the vicinity of Armidale which do not show the effects of thermal metamorphism. There are a number of outcrops between the University and the batholith which are approximately a mile from the contact and these are the only representatives of unmetamorphosed lavas seen by the author. Unfortunately it was not possible to study them in detail.

Just north of the University is a light grey rock which is very rich in calcite both in amygdales and throughout the groundmass. It is fine grained with an irregular texture outlined by tiny labradorite laths (up to 0·5 mm. long) and contains abundant chlorite, leucoxene and ilmenite.

A dark green massive rock occurs in a creek about a quarter of a mile north of this outcrop. This is much coarser than the lava mentioned above and is similar to the Dumaresq dolerite in texture. Albite laths up to 2 mm. long show zoning, twinning on combinations of the Albite and Carlsbad laws and some bending. Some plagioclase laths have been partially replaced by calcite. There is abundant brown hornblende with patches of chlorite, granules of epidote, and needles of tremolite.

Further to the north there occur extremely fine grained lavas rich in fibrous brown hornblende with labradorite.

The thermally altered lavas were both basaltic and spilitic in composition prior to metamorphism but they have been so strongly altered that it is not possible to determine the exact nature of the original basic rock.

Conclusions.

The basaltic lavas originally consisted of augite, labradorite and ilmenite and in the spilites this assemblage was modified to hornblende, albite and ilmenite. The first stage of metamorphism is typified by the association hornblende plus albite due either to the simple recrystallization of the spilites or to the alteration of the plagioclase and pyroxene of the basalts. This is followed by the association diopside plus andesine representing higher grade conditions. This new assemblage forms veins cutting the hornblende-albite rocks and also occurs as coarse granoblastic patches.

Failure to achieve equilibrium is apparent in many cases as diopside is accompanied by pure albite as well as andesine (Ab_{60-65}). Original augite and labradorite persist in rocks containing diopside and grossular. Some rocks contain albite and labradorite or albite and andesine.

The next stage in the metamorphism was the formation of grossular in those rocks within 500 feet of the monzonite contact. The garnet is only found intimately associated with calcite in amygdales and forms reaction rims due to combination of lime from within the amygdales and alumina and silica from the groundmass. It is possible that the garnet was formed by reaction of calcite with pyroxene plus the anorthite portion of plagioclase thus :

$$\text{Calcite} + \text{diopside} + \text{anorthite} \rightarrow \text{grossular etc.}$$
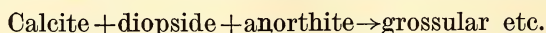
It is probably more accurate however to represent the reaction thus :

$$\text{calcite} + \text{alumina} + \text{silica} + \text{oxygen} \rightarrow \text{grossular} + \text{carbon dioxide.}$$

In one rock, garnet appeared to have formed directly from augite, and this might be represented as follows :

$$\text{augite} + \text{anorthite} \rightarrow \text{garnet} + \text{quartz.}$$
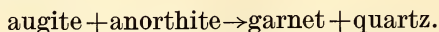
The final stage of alteration was the introduction of halogen which resulted in the alteration of plagioclase to scapolite. The mineral occurs in rocks

showing all degrees of alteration but occurs most abundantly in the hornfelses most remote from the monzonite.

The chemical analyses in Table 1 outline the chemical changes during metamorphism. Nos. 6732 and 6733 are the least altered and may have originally been basalt and spilite. It is quite possible that all the hornfelses were originally normal basalts and that all the alteration is due to the granites, thus the $6\cdot86\%$ Na_2O in 6733 would represent an introduction of soda during thermal metamorphism. An all too brief study of the rocks near the University suggests that both normal and spilitic basalts occurred prior to metamorphism but this is by no means certain. The most important difference between the
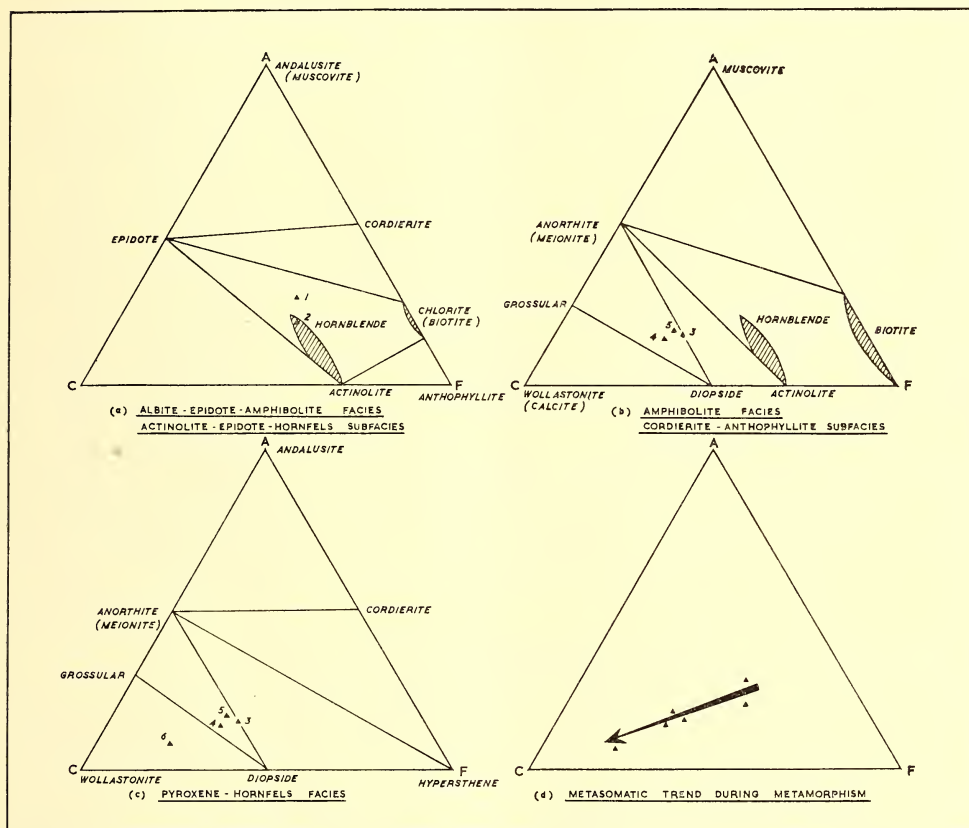
Text-fig. 3.—Compositions of the basic hornfelses plotted on A–C–F diagrams. The rocks 4 and 5 may lie in either of two facies as shown. The lime metasomatism accompanying metamorphism is clearly indicated by the analyses.

high and low grade hornfelses is in the lime content (from $5\cdot05\%$ in the lowest and $33\cdot30\%$ in the highest) and this lime metasomatism is illustrated in Fig. III where the analyses have been plotted on an A-C-F diagram following Turner (1948). The lime metasomatism resulted in the formation of diopside, plagioclase, grossular, wollastonite and calcite. Apart from the increase in lime the only notable addition was of chlorine leading to the development of scapolite. The highest chlorine content is, however, only $0\cdot15\%$ and thus probably some of the carbon dioxide present is in the scapolite. The higher grade rocks contain slightly less silica, soda and alumina but there is no significant change in the minor elements titanium, chromium and vanadium.

In one specimen the scattered small diopside granules have grown together to give a granoblastic aggregate of diopside and scapolite and it is interesting to note that strikingly similar diopside-scapolite rocks have formed by the regional metamorphism of dolomitic sediments in the Kanmantoo Group in South Australia and at Cloncurry, Queensland (Edwards and Baker, 1953). The lime-rich Group B hornfelses of Puddledock (Spry, 1953) with their wollastonite-grossular-diopside assemblage also strongly resemble altered lime-rich sediments and the lime metasomatism which allowed the change from hornblende plus albite to diopside plus andesine, became extensive in these rocks.

TABLE I.

	6732	6733	6734	6735	6736	6987
SiO_2	46·48	53·41	44·56	41·66	42·81	44·72
Al_2O_3	15·97	19·80	13·65	13·25	14·32	4·78
Fe_2O_3	1·93	1·61	1·70	3·68	0·90	1·92
FeO	8·02	4·85	6·19	3·75	7·26	4·68
MnO	0·22	0·12	0·15	0·19	0·17	0·41
MgO	7·90	2·02	6·13	2·88	4·34	2·51
CaO	13·02	5·05	20·90	26·66	22·11	33·30
Na_2O	2·60	6·86	1·70	1·86	1·83	0·20
K_2O	0·20	1·77	0·40	1·40	0·54	0·09
TiO_2	0·75	3·40	1·60	0·88	2·11	0·20
P_2O_5	0·09	0·03	Tr	0·36	0·13	0·14
H_2O+	2·13	0·77	1·67	0·67	1·46	1·68
H_2O-	0·20	0·30	0·15	0·35	0·28	0·14
Cl	0·05	Tr	0·07	0·11	0·15	N.d.
SO_3	0·08	—	—	—	—	N.d.
CO_2	0·38	0·42	1·02	2·70	1·55	* 5·04
Cr_2O_3	0·06	0·005	0·07	0·04	—	N.d.
V_2O_3	0·07	0·04	0·12	0·06	—	N.d.
	100·15	100·46	100·11	100·50	99·96	99·81

6732 Basic hornfels (labradorite, hornblende) Tilbuster, anal. J. H. Pyle.
6733 Basic hornfels (albite, hornblende) Tilbuster, anal. J. H. Pyle.
6734 Basic hornfels (andesine, diopside, grossular) Tilbuster, anal. J. H. Pyle.
6735 Basic hornfels (andesine, diopside, grossular, calcite) Tilbuster, J. H. Pyle.
6736 Basic hornfels (diopside, hornblende, andesine, scapolite) Puddledock, anal. J. H. Pyle.
6987 Basic hornfels (calcite, wollastonite, pyroxene, grossular) Puddledock, anal. W. St. C Manson.

In some cases the composition of the scapolite is similar to the parent plagioclase (as regards lime and soda) but in other cases there is a considerable difference implying addition of soda as well as halogen. It is seen here that plagioclase is altered to scapolite in the following manner.

andesine $Ab_{60} \rightarrow$ scapolite Ma_{55}
labradorite $Ab_{40} \rightarrow$ scapolite Ma_{65}
albite $Ab_{100} \rightarrow$ scapolite Ma_{60}
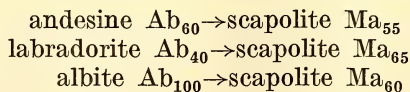
The scapolite in the lower grade rocks appears to be generally richer in soda even when in actual contact with free calcite. This suggests that perhaps the composition of the scapolite may be dependent more upon physical than chemical conditions, i.e. more upon temperature than bulk composition. Thus the lime content of the scapolite may increase as the grade of metamorphism increases in a similar fashion to the response of the plagioclases in metamorphism. It is not possible to prove this here as the failure to achieve equilibrium is evident

in most rocks. Scapolitization is common, but is most notable away from the igneous contact (blue tourmaline occurs similarly). It appears that there was a passage for chlorine and boron from the monzonite through the lava in the north-eastern corner.

Superficially the greywackes appear to be less altered than the basic rocks for three reasons. Firstly, they retain their original clastic texture without coarse recrystallization. Secondly, the metamorphic minerals are not strongly developed in size and amount. Thirdly, the composition of the rocks is such that the new minerals are biotite, hornblende and plagioclase without the more conspicuous minerals such as cordierite, almandine and andalusite which are stable in rocks richer in alumina at the same grade. The assemblage biotite-hornblende-plagioclase indicates that these rocks lie in the amphibolite facies and do not extend down into a lower facies where albite and epidote occur, nor up into a higher facies where hornblende is no longer stable and either diopside, hypersthene or cordierite would be formed. The sediments at Tilbuster and Dumaresq are less altered than those at Puddledock where complete recrystallization has obliterated the clastic texture.

As at Puddledock, these rocks cannot be classified satisfactorily according to the facies principles of Turner (1948) owing to the failure of many rocks to achieve equilibrium and to the lack of critical mineral assemblages. The more critical assemblages in the greywackes suggests that all the basic hornfelses lie in the amphibolite facies, although those north of the garnet limit may lie in the lower part of the actinolite-epidote hornfels sub-facies of the albite-epidote amphibolite facies. It is possible also that some rocks containing the assemblage diopside-andesine-grossular may have reached the pyroxene hornfels facies.

Comparing these rocks with the basic hornfelses from Puddledock it is apparent that although the rocks south of the garnet limit at Tilbuster resemble the Group A hornfelses at Puddledock, the Group B hornfelses of the latter area have no counterpart here. The hornfelses north of the garnet limit are somewhat lower in grade than those at Puddledock although the scapolitized varieties at Tilbuster are identical with the Group A variety (3) rocks from Puddledock.

The thermal metamorphism of the dolerite shows that it is older than the granite and it is not a late stage basic differentiate. It may be regarded as being either contemporaneous with the lava and thus marking feeder channels to the flows or as the intrusive form of the same magma introduced during the folding. The association of spilite and dolerite was noticed in each of the areas examined at Armidale and this suggests that the two are closely related genetically. The author suggested that the dolerite at Puddledock was post-granite in age because it lay within high grade hornfelses but was not metamorphosed by the closely adjacent monzonite, and so at present there appear to have been two distinct periods of basic intrusion.

Mineragraphic Division of C.S.I.R.O. for his determinations on the polished sections. Dr. G. D. Osborne and Professor S. Warren Carey have been most helpful with critical discussion of the manuscript.

EXPLANATION OF PLATE.

PLATE IV.

Fig. 1.—Basic hornfels showing a calcite-filled amygdale with a garnet rim and crystals of ilmenite with coronas of sphene. $\times 65$.

Fig. 2.—Sheared basic hornfels with a schistose groundmass and an augen shaped amygdale containing a recrystallized area composed of plagioclase, amphibole and sphene. $\times 65$.

Fig. 3.—Pseudo-ophitic texture shown by hornblende with inclusions of plagioclase and a little diopside. $\times 65$.

Fig. 4.—Granoblastic diopside-scapolite rock. $\times 65$.

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PHOTOGRAPHIC LIGHT CURVE OF THE ECLIPSING BINARY GW CARINAE.

By Lawrence Drake, s.j.

(Communicated by T. N. Burke-Gaffney, S.J.)

The writer estimated this eclipsing binary on 344 plates taken at Riverview College Observatory from 1937 to 1954 with the R and G cameras (Zeiss Astro-triplets).

COMPARISON STARS.

The comparison stars are listed in Table 1, with their CPD number, HD number, spectral class and photographic magnitude. The magnitudes were determined by O'Connell (communicated privately) with S. Gaposchkin's sequence for Selected Area 192 (*Harv. An.* 89).

TABLE 1.

Comparison Stars for GW Carinae.

Star.	CPD.	HD.	Spectrum.	Pg. Mag.
				m
GW Car	−59 1428	83475	B8	
a	−58 1583	83389	A0	9·55
b	−59 1454	84331	B9	9·63
c	−59 1433	83587	F0	9·95
d	−59 1436	83642	A0	10·02
e	−59 1421	83251	A0	10·28
f	−59 1429	83502	A0	10·52
g	−59 1424	304676	B9	10·77
h	−59 1438			11·05

MEAN POINTS.

Times were reduced to the sun. The phases were calculated with zero epoch J.D. 2,420,000, and period $1^{\mathrm{d}}\cdot128912$ (determined by O'Connell and communicated privately). The mean points are given in Table 2, and are shown in Figure 1.

TABLE 2.

Mean Points for GW Carinae.

Phase.	Pg. Mag.	No.	Phase.	Pg. Mag.	No.
P	m		P	m	
0·0303	9·766	20	0·5269	9·782	18
0·0871	9·700	20	0·5818	9·698	19
0·1410	9·713	20	0·6520	9·688	19
0·2013	9·685	20	0·7046	9·723	18
0·2470	9·740	16	0·7462	9·791	16
0·2901	9·828	9	0·7874	9·902	8
0·3130	9·990	10	0·8155	9·918	5
0·3396	10·042	9	0·8413	10·239	7
0·3595	10·181	8	0·8613	10·380	6
0·3908	10·231	8	0·8828	10·629	8
0·4153	10·148	8	0·9038	10·628	6
0·4361	9·969	8	0·9140	10·493	6
0·4515	10·024	7	0·9351	10·302	8
0·4657	9·931	7	0·9482	10·155	6
0·4866	9·844	8	0·9700	10·005	8
			0·9834	9·854	8
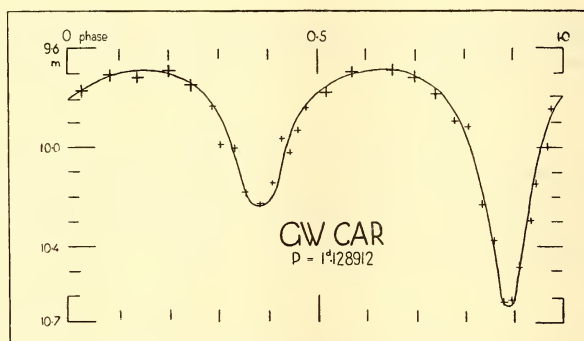
Text-fig. 1.—Light Curve of GW Carinae.

Abscissæ are decimals of phase and ordinates photographic
magnitudes. Large crosses denote the mean of 16 to 20
estimates, small crosses the mean of from 5 to 10.

MEAN LIGHT CURVE.

The maxima and minima from the mean light curve, and their phases,
are given in Table 3.

TABLE 3.

From Mean Light Curve.

	Phase.	Mag.
	P	m
Max.	—	9·69
Min. I	0·893	10·65
Min. II	0·388	10·24

THE NORMAL VIBRATION FREQUENCIES OF XY_3Z_3 MOLECULES BELONGING TO THE POINT GROUP D_{3h}.

By A. Keane.

School of Mathematics, New South Wales University of Technology.

With four Text-figures.

SUMMARY.

Formulæ are presented for the calculation of the frequencies of the normal modes of vibration of XY_3Z_3 molecules belonging to the point group D_{3h}. The results have been obtained on the assumption of a valence force field and by a method which is in essence that of using symmetry coordinates.

INTRODUCTION.

Most plane molecules of the form XY_3Z_3 belong to the point group C_{3h} in which the X-Y-Z atoms are not in a straight line. However, the molecule boron tricyanide $B(CN)_3$ which has recently been prepared (Chaigneau, 1954) possibly belongs to the point group D_{3h}. Other possibilities are the tricyano-cuprous ion and the tricyanoargentus ion.

For molecules, such as methyl borate, with a kernel of heavy atoms belonging to the point group C_{3h}, the equations of this paper should not lead to any serious error when used to identify the frequencies in the infra-red and Raman spectra with specific vibrations of the molecules.

Using the terminology of Herzberg (1945), we have that the vibration of the XY_3Z_3 molecules can be represented symbolically by

$$2A_1' + A_2' + 2A_2'' + 4E' + E''.$$

We thus have five non-degenerate and five degenerate vibrations accounting for the fifteen degrees of freedom of the molecule.

Throughout the following calculations we take m_x, m_y, m_z as the masses of the X, Y, Z atoms and p, q as the equilibrium lengths of the X-Y, Y-Z bonds respectively. We denote by a_1, a_2 the force constants for the stretching of the X-Y, the Y-Z bonds; a_3, a_4 the force constants for altering the angles YXY and XYZ in the plane of the molecule; a_5, a_6 the force constants for altering the angles made by the XY and YZ bonds with the plane.

We take x and y axes in the plane and the z axis through the X atom perpendicular to the plane.

VIBRATIONS OF SPECIES A_1'.

For this species the vibrations are in the plane of the molecule and are symmetrical with respect to the z axis. Hence the X atom is fixed. Further, the vibrations are symmetrical with respect to the X-Y-Z bonds, so that only stretching is allowed. We need therefore consider only one X-Y-Z bond.

Q

With the extensions shown in Text-figure 1.

$$2T = m_y\dot{\alpha}^2 + m_z(\dot{\alpha} + \dot{\beta})^2$$
$$2V = a_1\alpha^2 + a_2\beta^2$$

which yields for the vibration frequencies

$$\lambda_1 + \lambda_2 = \frac{a_1 m_z + a_2(m_y + m_z)}{m_y m_z}$$

$$\lambda_1 \lambda_2 = \frac{a_1 a_2}{m_y m_z}$$

Text-fig. 1.

VIBRATIONS OF SPECIES A_2'.

Here again the motion is in the plane of the molecule and the X atom is fixed. The motions of the Y and Z atoms must be perpendicular to the X-Y-Z bond, so that only changes in bond angles are allowable. However, as the motion is to be symmetric with respect to the z axis, there must be no change in the YXY angles. Again we need only one XYZ group as follows :—
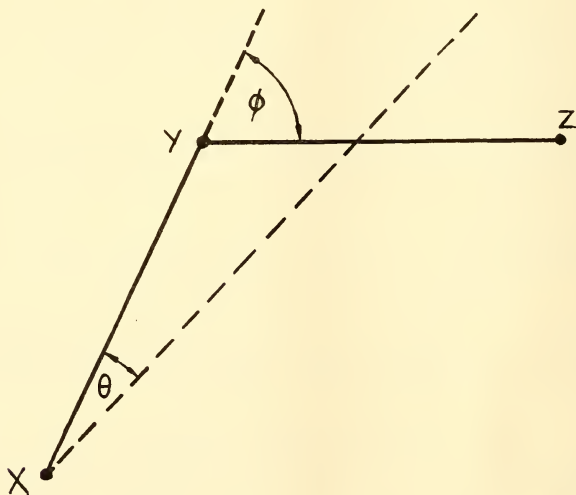
Text-fig. 2.

We eliminate θ (Text-fig. 2) from the kinetic energy by the condition that there should be no resultant angular momentum and obtain

$$2T = \frac{m_y m_z p^2 q^2}{m_y p^2 + m_z(p+q)^2}\dot{\varphi}^2$$

$$2V = a_4\varphi^2$$

$$\therefore \lambda_3 = \frac{a_4\{m_y p^2 + m_z(p+q)^2\}}{m_y m_z p^2 q^2}$$

VIBRATIONS OF SPECIES A_2''.

In this case the motion of the atoms is perpendicular to the plane of the molecule, and must be symmetrical with respect to the z axis. For this species the X atom is allowed to vibrate and the motion of the molecule must be such that there is no resultant translational momentum in the z direction. It is again permissible to treat one X-Y-Z group provided we take the mass of the X atom as $\frac{1}{3}m_x$.
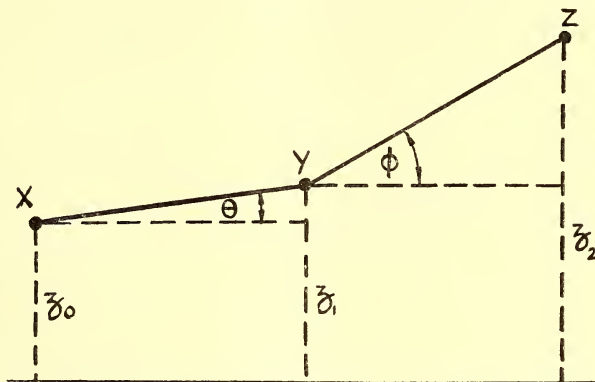
Text-fig. 3.

We first express the kinetic energy of the system in terms of the coordinates z_0, z_1, z_2 (Text-fig. 3). The kinetic energy can then be expressed in terms of the internal coordinates θ, φ by using the condition of no translational momentum.

For this species we find

$$2T = m_y p^2\dot\theta^2 + m_z(p\dot\theta + q\dot\varphi)^2 - \frac{3\{(m_y+m_z)p\dot\theta + m_z q\dot\varphi\}^2}{m_x+3m_y+3m_z}$$

$$2V = a_5\theta^2 + a_6\varphi^2$$

yielding

$$\lambda_4 + \lambda_5 = \frac{a_5 m_z(m_x+3m_y)q^2 + a_6 m_x(m_y+m_z)p^2}{m_x m_y m_z p^2 q^2}$$

$$\lambda_4\lambda_5 = \frac{a_5 a_6}{m_x m_y m_z p^2 q^2}(m_x+3m_y+3m_z).$$

VIBRATIONS OF SPECIES E'.

For the species E' the atoms vibrate in the plane of the molecule. Because of the degeneracy of the vibrations we may take the X atoms to move only in the direction of one X-Y-Z group and have the motion of the other two Y-Z groups anti-symmetrical about this line. This procedure is allowable since the degeneracy arises from the fact that the same frequency is obtained no matter which is the direction of vibration of the X atom.

The type of motion postulated eliminates translational momentum in the x direction.

The condition that there must be no resultant translational momentum in the y direction enables us to express the kinetic energy in terms of α, β, γ, δ, θ, φ.

Thus

$$2T = m_y(\dot{\alpha}^2 + 2\dot{\beta}^2 + 2p^2\dot{\theta}^2)$$

$$+ m_z\{\dot{\alpha}^2 + 2\dot{\alpha}\dot{\gamma} + \dot{\gamma}^2 + 2\dot{\beta}^2 + 4\dot{\beta}\dot{\delta} + 2\dot{\delta}^2 + 2p^2\dot{\theta}^2 + 2q^2(\dot{\theta}+\dot{\varphi})^2 + 4pq\dot{\theta}(\dot{\theta}+\dot{\varphi})\}$$

$$- \frac{[m_y(-\dot{\alpha}+\dot{\beta}-\sqrt{3}p\dot{\theta}) + m_z(-\dot{\alpha}-\dot{\gamma}+\dot{\beta}+\dot{\delta}-\sqrt{3}p\dot{\theta}-\sqrt{3}q(\dot{\theta}+\dot{\varphi}))]}{m_x + 3m_y + 3m_z}$$

$$2V = a_1(\alpha^2 + 2\beta^2) + a_2(\gamma^2 + 2\delta^2) + 6a_3\theta^2 + 2a_4\varphi^2.$$

We have here six coordinates and wish to find only four vibrational frequencies. The other two vibrations involved can easily be seen to be those of species A_1'.
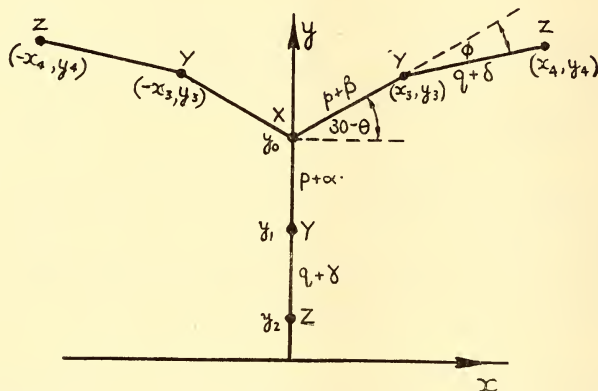
Text-fig. 4.

On solving the secular equation we reproduce the results for species A_1' and in addition find for the vibrations of species E'.

$$\lambda_6 + \lambda_7 + \lambda_8 + \lambda_9$$

$$= \frac{1}{2m_x m_y m_z p^2 q^2}[m_z(2m_x + 3m_y)p^2 q^2 a_1 + 2m_x(m_y + m_z)p^2 q^2 a_2$$

$$+ 3m_z(2m_x + 3m_y)q^2 a_3 + \{2m_x m_y p^2 + 2m_x m_z(p+q)^2 + 3m_y m_z q^2\}a_4]$$

$$\lambda_6\lambda_7 + \lambda_7\lambda_8 + \lambda_8\lambda_9 + \lambda_6\lambda_8 + \lambda_6\lambda_9 + \lambda_7\lambda_9$$

$$= \frac{1}{2m_x m_y^2 m_z^2 p^2 q^2}[m_y m_z(2m_x + 3m_y + 3m_z)p^2 q^2 a_1 a_2 + 6m_z(m_y + m_z)(m_x + 3m_y)q^2 a_2 a_3$$

$$+ 3m_y m_z(2m_x + 3m_y + 3m_z)a_3 a_4 + 6m_z^2(m_x + 3m_y)q^2 a_1 a_3$$

$$+ m_z\{(2m_x + 3m_y)\{m_y p^2 + m_z(p+q)^2\} + 3m_y m_z q^2\}a_1 a_4$$

$$+ (m_y + m_z)\{2m_x m_y p^2 + 2m_x m_z(p+q)^2 + 3m_y m_z q^2\}a_2 a_4]$$

$$\lambda_6\lambda_7\lambda_8 + \lambda_7\lambda_8\lambda_9 + \lambda_8\lambda_9\lambda_6 + \lambda_9\lambda_6\lambda_7$$

$$= \frac{1}{2m_x m_y^2 m_z^2 p^2 q^2}[3m_z(2m_x + 6m_y + 3m_z)q^2 a_1 a_2 a_3$$

$$+ 3(m_y + m_z)(2m_x + 3m_y + 3m_z)a_2 a_3 a_4$$

$$+ 3m_z(2m_x + 6m_y + 3m_z)a_3 a_4 a_1$$

$$+ \{(2m_x + 3m_y + 3m_z)\{m_y p^2 + m_z(p+q)^2\} + 3m_y m_z q^2\}a_4 a_1 a_2]$$

$$\lambda_6\lambda_7\lambda_8\lambda_9$$

$$= \frac{3(m_x + 3m_y + 3m_z)}{m_x m_y^2 m_z^2 p^2 q^2}a_1 a_2 a_3 a_4.$$

Vibrations of Species E''.

This is a degenerate vibration in which the atoms move perpendicular to the plane and which is anti-symmetrical with respect to the z axis. For this motion the X atom must be fixed, and the frequency of the vibration can be found by considering only one X-Y-Z group. With the condition that there must be no resultant angular momentum about the x or y axes, the problem is identical with that for determining the normal vibrations of species A_2', the only difference being that now

$$2V = a_6\varphi^2$$

so that

$$\lambda_{10} = \frac{a_6\{m_y p^2 + m_z(p+q)^2\}}{m_y m_z p^2 q^2}.$$

Acknowledgement.

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DETERMINATION OF FLOW–INDEX IN A MINE.

By C. M. Groden, M.Sc.

School of Mathematics, New South Wales University of Technology.

With one Text-figure.

I. Introduction.

In a recent paper Peascod and Keane (1955) established a relationship between the ventilating pressure and the quantity of air reaching the working face in a mine, due consideration being paid to the leakage of air through the porous barrier between the intake and return. This relationship is based on the assumption that, in the airways, the equation for turbulent flow at a point C (say) is given by

$$\frac{dP}{dl} = -r_1 Q^2$$

where $\frac{dP}{dl}$ is the pressure gradient, Q the quantity of air flowing past the point C per unit time, and r_1 is a constant.

Investigations of Reynolds (1953) and Lees (1933) show that for turbulent flow in a pipe a closer representation to the facts is given by the equation

$$\frac{dP}{dl} = -r_1 Q^n \qquad \dots\dots\dots\dots\dots\dots\dots \quad (1)$$

where n is a number lying between $1\cdot7$ and 2. This index depends on the degree of smoothness of the surface of the pipe and as the roughness increases the value of n tends towards 2.

Measurements of P and Q at any point in the airway can be made, and the paramount problem then is to predict the change in one quantity brought about by a change in the other. Obviously, an approximation for n close to the value pertaining in the airway will allow predictions of more accuracy than would be possible if the value of n were assumed to be always equal to 2.

It is felt, therefore, that the effect of leakage on the quantity of air reaching working face should be investigated for any value of n, and moreover a method developed to allow determination of the value of n in any given case.

II. Notation and Assumptions.

Consider a mine consisting of two parallel roadways, an intake and return of similar construction, i.e. we assume the same value of r_1 in each. We shall neglect any density changes in the air in the roadways and assume that the barrier between intake and return is a uniformly porous medium.

Let AB be the intake and A_1B_1 the return (Fig. 1), each of the length L, and BB_1 is small compared with AB.

Let the quantity of air, per unit time, passing A be Q_0 and that passing working face B be Q_E. We shall define the efficiency of the ventilating system as

$$\frac{Q_E}{Q_0} = k \text{ (say)} \quad \dots\dots\dots\dots\dots\dots \quad (2)$$

$Q_0 - Q_E$ is therefore the loss due to leakage. As the resistances of both airways are the same, the pressure drop in the intake will be the same as that in the return. Let the pressure at the inlet A be P_0 and, for convenience, let the pressure at the outlet A_1 be $-P_0$; that is, the quantity Q_E reaches the working face at zero pressure. Also, as BB_1 is small compared with AB, we can assume that there is no pressure drop across the working face.
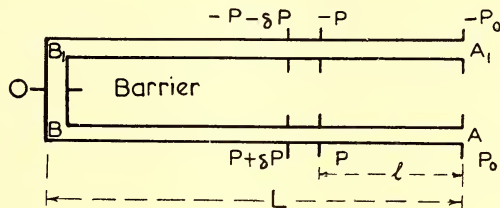
Text-fig. 1.

In his investigations Storrow (1919) has shown that in any leakage through a porous goaf the rate of flow of the air depends directly on the difference of pressure on either side and on the length of the wall, that is, the air flow through a wall of length δl will be

$$\delta Q = -\frac{1}{r_2} \delta l \ (P_1 - P_2) \quad \dots\dots\dots\dots\dots \quad (3)$$

where P_1 and P_2 are the pressures on either side of the goaf and r_2 is a constant. In order to simplify our formulæ we shall write

$$R_1 = L r_1 \quad \dots\dots\dots\dots\dots\dots \quad (4)$$

$$R_2 = \frac{r_2}{L} \quad \dots\dots\dots\dots\dots\dots \quad (5)$$

These definitions of R_1 and R_2 will avoid the introduction of L explicitly in our final result. (In mining terminology R_1 is called the resistance of the airway.)

III. The Pressure-Quantity Equation.

We now refer to Figure 1.

Let Q be the quantity of air passing a point of the intake, distance l from the inlet, where the pressure is P; Q_0 be the quantity entering the mine at pressure P_0; and Q_E be the quantity reaching the working face at zero pressure.

Consider a section of length δl in the intake, where the pressure changes from P to $P + \delta P$. In the corresponding section of the return the pressure changes from $-P$ to $-P - \delta P$. If δQ is the quantity lost in this element of the airway, we see that this quantity δQ passes from the intake to the return through the porous barrier under the influence of a mean pressure difference of $2P + \delta P$. Using equation (2) and, taking first order terms only, we have for the quantity flowing through the barrier from an element of length δl

$$\delta Q = -\frac{2P}{r_2} \delta l \quad \dots\dots\dots\dots\dots \quad (6)$$

Also, using equation (1) we have for the flow in the intake through a pressure drop of δP

$$\delta P = -r_1 \delta l Q^n \quad \dots\dots\dots\dots\dots\dots \quad (7)$$

Combining (7) and (6) we obtain the differential equation connecting pressure and quantity,

$$\frac{dQ}{dP} = \frac{2}{r_1 r_2} \frac{P}{Q^n}$$

which becomes, on using equations (4) and (5),

$$Q^n \frac{dQ}{dP} - \frac{2}{R_1 R_2} P = 0 \quad \dots\dots\dots\dots\dots \quad (8)$$

By the method of separating the variables we have

$$Q^{n+1} - \frac{(n+1)P^2}{R_1 R_2} = \text{const.} = Q_E^{n+1} \quad \dots\dots\dots\dots \quad (9)$$

from which we finally obtain

$$P = \sqrt{\frac{R_1 R_2}{n+1}(Q^{n+1} - Q_E^{n+1})} \quad \dots\dots\dots\dots \quad (10)$$

IV. The Relation Between Q_0 and Q_E.

From (5) and (4) it follows that

$$\int_{Q_0}^{Q_E} \frac{dQ}{P} = \frac{-2}{LR_2} \int_0^L dl = \frac{-2}{R_2} ;$$

which, on using (9), becomes

$$\int_{Q_E}^{Q_0} \frac{dQ}{\sqrt{(Q^{n+1} - Q_E^{n+1})}} = 2\sqrt{\frac{R_1}{R_2(n+1)}} \quad \dots\dots\dots \quad (11)$$

In order to evaluate the left-hand member of the equation (11) we expand the integrand in a binomial series and integrate term by term, to obtain

$$\sqrt{\frac{R_1}{R_2(n+1)}} \cdot Q_E^{\frac{1}{2}(n-1)} = \frac{1}{n-1}\left\{ {}_2F_1\left\{\frac{1}{2}, \frac{n-1}{2n+2} ; \frac{3n+1}{2n+2} ; 1\right\} \right.$$

$$\left. - k^{\frac{1}{2}(n-1)} {}_2F_1\left\{\frac{1}{2}, \frac{n-1}{2n+2} ; \frac{3n+1}{2n+2} ; k^{n+1}\right\}\right\}$$

where k is given by equation (2) and

$${}_2F_1\{a, b ; c ; z\} = 1 + \sum_{n=1}^{\infty} \frac{a(a+1)\dots(a+n-1) \cdot b(b+1)\dots(b+n-1)}{c(c+1)\dots(c+n-1)} \frac{z^n}{n!}$$

is the hypergeometric function. Solving the last equation for Q_E we then have

$$Q_E = \left[\frac{R_2(n+1)}{R_1(n-1)^2}\left\{{}_2F_1\left\{\frac{1}{2}, \frac{n-1}{2n+2} ; \frac{3n+1}{2n+2} ; 1\right\}\right.\right.$$

$$\left.\left. - k^{\frac{1}{2}(n-1)} \cdot {}_2F_1\left\{\frac{1}{2}, \frac{n-1}{2n+2} ; \frac{3n+1}{2n+2} ; k^{n+1}\right\}\right\}^2\right]^{\frac{1}{n-1}} \quad \dots \quad (12)$$

from which Q_E can be calculated for a given value of n and k. Then, from (2), $Q_0=Q_E/k$ and from (10), for $Q=Q_0$, the value of P_0 can be obtained

$$P_0= \sqrt{\frac{R_1R_2}{n+1}(Q_0^{n+1}-Q_E^{n+1})} \quad \ldots\ldots\ldots\ldots (13)$$

V. TABULATION OF RESULTS.

The following tables give the values of

$$Q_E \div \left(\frac{R_2}{R_1}\right)^{\frac{1}{n-1}}; \quad Q_0 \div \left(\frac{R_2}{R_1}\right)^{\frac{1}{n-1}}; \quad P_0 \div \left(\frac{R_2^n}{R_1}\right)^{\frac{1}{n-1}}$$

for $n=1\cdot7$, $n=1\cdot8$ and $n=1\cdot9$ respectively, for values of k ranging from 0 to 1 at the interval of $0\cdot1$.

TABLE 1.

$n=1\cdot7$.

$k=\dfrac{QE}{Q_0}$	$P_0 \div \left(\dfrac{R_2^{1\cdot7}}{R_1}\right)^{1/0.7}$	$Q_0 \div \left(\dfrac{R_2}{R_1}\right)^{1/0.7}$	$Q_E \div \left(\dfrac{R_2}{R_1}\right)^{1/0.7}$
0	∞	∞	18·0
0·1	102	45·5	4·55
0·2	20·0	13·4	2·67
0·3	6·21	5·67	1·70
0·4	2·30	2·77	1·11
0·5	0·905	1·43	0·714
0·6	0·352	0·742	0·445
0·7	0·124	0·367	0·257
0·8	0·029	0·139	0·111
0·9	0·005	0·048	0·043
1·0	0	0	0

TABLE 2.

$n=1\cdot8$.

k	$P_0 \div \left(\dfrac{R_2^{1\cdot8}}{R_1}\right)^{1/0.8}$	$Q_0 \div \left(\dfrac{R_2}{R_1}\right)^{1/0.8}$	$Q_E \div \left(\dfrac{R_2}{R_1}\right)^{1/0.8}$
0	∞	∞	9·68
0·1	86·0	34·8	3·48
0·2	17·5	11·2	2·24
0·3	5·73	5·09	1·53
0·4	2·26	2·64	1·06
0·5	0·929	1·45	0·725
0·6	0·380	0·817	0·481
0·7	0·144	0·426	0·298
0·8	0·043	0·201	0·161
0·9	0·008	0·077	0·070
1·0	0	0	0

TABLE 3.

$n = 1 \cdot 9$.

k	$P_0 \div \left(\dfrac{R_2^{1 \cdot 9}}{R_1}\right)^{1/0.9}$	$Q_0 \div \left(\dfrac{R_2}{R_1}\right)^{1/0.9}$	$Q_E \div \left(\dfrac{R_2}{R_1}\right)^{1/0.9}$
0	∞	∞	6·20
0·1	75·3	28·4	2·84
0·2	16·1	9·84	1·97
0·3	5·38	4·73	1·42
0·4	2·24	2·58	1·03
0·5	0·970	1·49	0·743
0·6	0·418	0·865	0·519
0·7	0·166	0·488	0·342
0·8	0·054	0·250	0·200
0·9	0·011	0·099	0·089
1·0	0	0	0

VI. DEDUCTIONS AND REMARKS

(i) *Maximum Quantity Reaching the Face.*

From the tables it follows that as Q_E increases the efficiency k of the mine ventilation system decreases. In the extreme case when $k \to 0$, Q_E tends to a maximum value, given by

$$Q_{E\max.} = \left[\frac{R_2(n+1)}{R_1(n-1)^2} \cdot {}_2F_1 \left\{\frac{1}{2}, \frac{n-1}{2n+2}; \frac{3n+1}{2n+2}; 1\right\}^2\right]^{\frac{1}{n-1}} \quad .. \quad (14)$$

(see equation (12)). Thus, for mines which satisfy our assumption there is a maximum quantity of air that can be brought to the working face.

(ii) *Determination of* n *in a Particular Mine.*

The equation (8)

$$Q^{n+1} - \frac{(n+1)P^2}{R_1 R_2} = \text{const.} = Q_E^{n+1}$$

is of the form

$$Q^{n+1} + AP^2 = B$$

where A and B are constant.

Taking readings at three different points in the intake : Q_1, P_1 ; Q_2, P_2 ; Q_3, P_3 respectively, we have the following three equations

$$Q_1^{n+1} + AP_1^2 = B$$
$$Q_2^{n+1} + AP_2^2 = B$$
$$Q_3^{n+1} + AP_3^2 = B$$

which are consistent only if

$$\begin{vmatrix} Q_1^{n+1} & P_1^2 & 1 \\ Q_2^{n+1} & P_2^2 & 1 \\ Q_3^{n+1} & P_3^2 & 1 \end{vmatrix} = 0$$

Thus

$$\frac{Q_2^{n+1} - Q_1^{n+1}}{Q_3^{n+1} - Q_1^{n+1}} = \frac{P_2^2 - P_1^2}{P_3^2 - P_1^2}$$

which can be transformed into

$$\frac{1 - \left(\dfrac{Q_2}{Q_1}\right)^{n+1}}{1 - \left(\dfrac{Q_3}{Q_1}\right)^{n+1}} = \frac{P_1^2 - P_2^2}{P_1^2 - P_3^2} \quad \dots\dots\dots\dots\dots (15)$$

From this equation n can be determined by successive approximations.

(iii) *Use of Tables.*

We take measurements of P and Q at three points in the intake, including the inlet A. By using equation (15), we first determine the index n and then the value of Q_E if this value cannot be obtained directly. The quotient $\dfrac{Q_E}{Q_0}$ gives the efficiency k of the mine. Using this value of k and the appropriate table, the values of R_1 and R_2 can be determined.

(iv) *Unequal Resistances in Intake and Return.*

The formulæ (12) and (13) and the calculated tables are still applicable if the resistances in the intake and the return are unequal. Low showed that in this case R_1 is to be replaced by the mean value of both resistances of the intake and return.

VII. Acknowledgements.

The author wishes to express his appreciation to Mr. A. Keane, from the School of Mathematics, New South Wales University of Technology, who suggested the topic of this paper.

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NOTE ON THE PRECEDING PAPER BY C. M. GRODEN.

By A. Keane.

School of Mathematics, New South Wales University of Technology.

For the particular case $n=2$ it is possible to obtain more useful relations in terms of Jacobean elliptic functions of modulus $\sin \pi/12$. Measuring the distance $x=L-l$ from the working face and following through the steps of Groden's analysis, we obtain in place of equations (10) and (11)

$$P^2=\frac{r_1 r_2}{3}(Q^3-Q_E^3) \quad \dots\dots\dots\dots\dots (10')$$

$$\int_1^{Q/Q_E}\frac{dz}{(z^3-1)^{\frac{1}{2}}}=2Q_E^{\frac{1}{2}}\sqrt{\frac{r_1}{3r_2}}\cdot x \quad \dots\dots\dots\dots (11')$$

The first member of equation (11′) is seen to be an elliptic integral and on expressing

$$z^3-1=\frac{1}{4\sqrt{3}}\{(\sqrt{3}-1+z)^2-(\sqrt{3}+1-z)^2\}.$$

$$\left\{\frac{2+\sqrt{3}}{4}(\sqrt{3}-1+z)^2-\frac{2-\sqrt{3}}{4}(\sqrt{3}+1-z)^2\right\}$$

and making the substitution $t=\dfrac{\sqrt{3}+1-z}{\sqrt{3}-1+z}$ is easily evaluated to yield

$$\frac{\sqrt{3}+1-Q/Q_E}{\sqrt{3}-1+Q/Q_E}=\mathrm{cn}\left(3^{\frac{1}{4}}2Q_E^{\frac{1}{2}}\sqrt{\frac{r_1}{3r_2}}\cdot x\right) \quad \dots\dots\dots (16)$$

If we denote the argument of the elliptic function in equation (16) by $\alpha.x$ and make use of equation (10′) we obtain the following parametric equations giving the pressure and quantity at all points in the airway

$$\left.\begin{array}{l}Q_E=\dfrac{\sqrt{3}}{4}\dfrac{r_2}{r_1}\alpha^2 \\[3mm] Q=\dfrac{\sqrt{3}}{4}\dfrac{r_2}{r_1}\alpha^2\left\{1+\sqrt{3}\,\dfrac{1-\mathrm{cn}\,\alpha x}{1+\mathrm{cn}\,\alpha x}\right\} \\[3mm] P=\dfrac{3}{4}\dfrac{r_2^2}{r_1}\alpha^3\,\dfrac{\mathrm{sn}\,\alpha x\;\mathrm{dn}\,\alpha x}{(1+\mathrm{cn}\,\alpha x)^2}\end{array}\right\} \quad \dots\dots\dots (17)$$

The values of Q_0 and P_0 follow immediately when $x=L$.

It is to be noted that for finding the pressures and quantities at various points in the interior of the mine, the parameter α here introduced has a definite advantage over the parameter $k = \dfrac{Q_E}{Q_0}$ used by Groden, but unfortunately its use is only possible when $n = 2$.

The upper limit for the face ventilation which can be obtained from equation (14) is quite easily reproduced from equations (17). When the ventilating pressure, $2P_0$, and the quantity of air entering the mine, Q_0, become indefinitely large we require $1 + \mathrm{cn}\, L\alpha$ to tend to zero. This implies $L\alpha = 2K$ where K is the complete elliptic integral of the first kind of modulus $\sin \pi/12$, and so from the first of equations (17)

$$Q_E = \sqrt{3} K^2 \frac{R_2}{R_1}$$

where $R_1 = r_1 L$ and $R_2 = \dfrac{r_2}{L}$. According to Whittaker and Watson, "Modern Analysis", p. 525, we find the result

$$K = 3^{-\frac{1}{4}} \frac{\pi^{\frac{1}{2}}}{2} \frac{\Gamma(\frac{1}{6})}{\Gamma(\frac{2}{3})},$$

so that

$$Q_E = \frac{\pi}{4} \left\{ \frac{\Gamma(\frac{1}{6})}{\Gamma(\frac{2}{3})} \right\}^2 \frac{R_2}{R_1}$$

BÆCKEA CITRIODORA : A NEW MEMBER OF THE MYRTACEÆ.

By A. R. Penfold
and J. L. Willis

Bæckea citriodora sp. nov.

Frutex parvus, diffusus, glaber, usque ad 30 cm. altus : foliis oppositis, decussatis, confertis, brevissime petiolatis ; petiolis non 1mm. excedentibus ; laminis oblongo-lanceolatis, raro 3mm. excedentibus, integris, planis vel depressis secus nervum primum, crassis, nervis obscuris, pellucido-punctatis ; odore citrato ; floribus parvis, vix folia excedentibus, solitariis in axillis foliorum ; pedicellis brevibus circa 0·5mm. longis ; bracteolis 2 deciduissimis basi ornatis ; tubo calycis glabro, semirotundo, ovarium adnato, circa 2mm. longo, subviride ; lobis calycis 5, parvis (0·2mm.–0·3mm.), subter incrassatis persistentibus ; petalis 5, albis, plus minusve orbicularibus, circa 1mm. diam., patentibus ; staminibus 5, petala non excedentibus, oppositis lobis calycis ; antheris versatilibus, subglobulosis, distinctis, profunde caniculatis, circa 0·25mm. longis, rimis 2 in caniculis dehiscentibus, filamentis complanatis circa 0·5mm. longis ; stylo erecto, capitato, persistente, in recessu centroso inserto ; ovario supra plano, 3-loculare, placentis axillaribus ; ovulis 2 in singulo loculo : capsula dehiscente tubo calycis persistente inclusa ; stylo etsi fructu aperto persistente ; seminibus fuscis, crustaceis, reniformibus, 1 in singulo loculo.

A small, diffuse, glabrous shrub up to 30cm. high ; leaves opposite, decussate, crowded, minutely petiolate, the petioles less than 1mm. long ; blades oblong-lanceolate, thick, flat or depressed along midrib, obtuse, rarely above 3mm. long, entire, pellucid-dotted, fragrant with a citronella-like odour when crushed, venation obscure ; flowers small, scarcely exceeding the length of the leaves, solitary, axillary, on short pedicels about 0·5mm. long, with two concave, very deciduous bracteoles at the base ; calyx-tube glabrous, hemispherical, adnate to the ovary, about 2mm. long, greenish ; calyx lobes 5, small (0·2–0·3mm.), thickened dorsally, persistent ; petals 5, white, more or less orbicular, about 1mm. in diameter, spreading ; stamens 5, not exceeding the petals, opposite the calyx lobes ; anthers nearly globular, distinct, deeply furrowed, about 0·25mm. long, opening in two parallel slits in the furrows, with a terminal gland, versatile ; filaments flattened, about 0·5mm. long ; style erect, persistent, inserted in a central depression, about 0·5mm. long, capitate ; ovary flat-topped, trilocular, 2 ovules per loculus, placentation axile ; capsule included in the persistent calyx tube, crowned by the persistent calyx lobes, dehiscent, the style persistent even after dehiscence ; seeds brown, crustaceous, reniform, one per loculus.

Location : New South Wales : Woodburn, A. R. Penfold, 2.5.1924 ; Wardell, Richmond River, J. Weller, 11.1943 and 17.1.1944 ; three miles east of 14 mile post on Coraki-Grafton Road, F. R. Morrison and J. L. Willis, 14.9.1949 ; Evans Head, F. R. Morrison and J. L. Willis, 16.9.1949 ; five miles north-west of Port Macquarie, D. K. Hammond, 12.1954 and 15.5.1955, Type.

This plant was first collected by A. R. Penfold in 1924 at Woodburn in northern New South Wales whilst investigating the cause of a citronella-like

taint in the milk produced on two properties in that district. The plant was found growing in an isolated patch and was considered to be the probable cause of the taint, as its leaves emitted a powerful odour of citronellal when crushed. Further patches of the same plant were also found at Evans Head and at Wardell on the Richmond River. The late E. Cheel, who examined the botanical material, decided it was a form of *Bæckea cunninghamii* Benth., but no detailed botanical investigation was carried out, and the plant was eventually exterminated some time before World War II by fires and the spread of population.

In 1949 F. R. Morrison and J. L. Willis located the plant again on the margin of a large swamp three miles east of the Coraki-Grafton Road and about 18 miles from the sea. It occurred in scattered patches along a strip of flat ground only about 50 yards wide, but extending for two or three miles along the swamp, and did not extend into the higher ground nearby. It was growing in grey, sandy soil in conjunction with *Philotheca australis* Rudge., *Calythrix tetragona* Labill., *Melaleuca thymifolia* Sm., and *Epacris microphylla* R.Br. Abundant floral material was collected, but no mature fruit was found. A further small patch was found at Evans Head growing on grey, sandy heathland, the concurrent species in this case being *Melaleuca nodosa* Sm., *Ricinocarpus pinifolius* Desf., *Leptospermum liversidgei* Baker and Smith, *Homoranthus virgatus* Schau., and *Philotheca australis*.

The location of several large areas near Port Macquarie by Mr. D. K. Hammond in 1954 and 1955 finally made available abundant flowering and fruiting material for a complete botanical examination. According to Mr. Hammond, the plant is confined to open, grey, sandy heathland in patches scattered over an area of several hundred acres.

The only other occurrence known to the authors is at Wardell on the Richmond River, northern New South Wales. The Wardell material collected by A. R. Penfold has been lost, but there are two specimens in the N.S.W. National Herbarium from this area, collected by J. Weller.

Bæckea citriodora, because of its five stamens opposite the calyx lobes, its trilocular ovary, subglobular, deep-furrowed anthers and dorsal thickening of the calyx lobes, falls naturally into Bentham's Section *Harmogia*. However, it differs from the other members of the section in its flattened filaments, and the presence of two ovules only in each loculus.

Although it shows some similarities to *Bæckea cunninghamii*, its nearest affinity appears to be *B. linearis* C. T. White. It is readily distinguished from the former by the shape and arrangement of leaves, the type of essential oil present, the flattened not filiform filaments, two ovules in each loculus instead of many, and only one seed per loculus instead of two. It differs from *B. linearis* in having oblong-lanceolate, not linear leaves and only two ovules in each loculus instead of about ten.

In the field, *Bæckea citriodora* is unmistakable on account of the powerful citronellal odour of the leaves, which is strikingly reminiscent of several other members of the Myrtaceæ, namely *Eucalyptus citriodora* Hook., *Leptospermum citratum* Chall., Cheel and Penf., and *Leptospermum liversidgei* variety " A ".

MELALEUCA VIRIDIFLORA GAERTN. AND ITS ESSENTIAL OILS.

By R. O. Hellyer
and H. H. G. McKern.
Museum of Applied Arts and Sciences, Sydney.

Summary.

The volatile leaf-oils steam-distilled from 18 individual trees of the species *Melaleuca viridiflora* Gaertn. from central coastal districts of New South Wales have been examined. As a result of this study, the existence of two morphologically indistinguishable varieties growing in association has been confirmed. One variety yields an oil consisting principally (90%) of (+)-nerolidol, although sometimes substantial amounts of (+)-linalool may be present; whilst the other gives an oil consisting of a mixture of cineole, (+)-α-pinene, (−)-limonene, dipentene, α-terpineol, viridiflorol, sesquiterpenes and benzaldehyde. The earlier work of Jones and Haenke and of Baker and Smith on this species is discussed. The question of the relationship of the viridiflorol-cineole variety to the Malaysian species yielding cajuput oil of commerce is raised.

Introduction.

The only recent work on the volatile oils of *Melaleuca viridiflora* Gaertn., the common " Broad-leaved Tea-tree " of the eastern Australian coast, is that of Jones, Harvey and Haenke (1935, 1937, 1938), who, as the result of the examination of oils from the foliage of single trees from south-east Queensland, showed the existence of two morphologically indistinguishable forms whose oils displayed a fundamental difference in chemical composition. One variety yielded a leaf oil consisting almost exclusively of linalool and nerolidol, whilst the other gave an oil consisting of a more complex mixture of cineole, (+)-α-pinene, (−)-limonene and dipentene, α-terpineol, viridiflorol and sesquiterpenes.

It has now been recently determined by Blake (1955) that the entire population of the Broad-leafed Tea-tree, from the southernmost extremity of its geographical range (approximately Sydney, N.S.W.) northwards to Maryborough and Fraser Island in Queensland, consists of one species. Hence the two specific names introduced by Baker (1913) and Baker and Smith (1913) to refer to trees in the Port Jackson-Gosford district of New South Wales (*M. smithii* R.T.B.), and in the Port Macquarie-Casino district (*M. maideni* R.T.B.), are redundant.

Jones and Haenke (1937) commented on the resemblance of their linalool-nerolidol variety with Baker and Smith's " *M. smithii* ", but remarked : " It is noteworthy, however, that in the publication of Baker and Smith regarding *M. smithii*, no record of the occurrence of linalool is mentioned, and presumably this constituent was absent from the oils examined by them from materials obtained near Sydney in New South Wales." In order to decide this point, and to determine more fully the nature of the constituents of oils from trees growing in localities for Baker's " *M. maideni* ", samples of foliage from 18 single trees were collected, nine from the Woy Woy district of New South Wales and nine from the Taree district further north.

THE VOLATILE OILS.

The examination of the oils of these trees shows that only two oil-groups may yet be distinguished. These are tentatively referred to here as the " nerolidol-linalool " group, and the " viridiflorol-cineole " group, using the most characteristic (not necessarily the most abundant) oil components to distinguish them.

The Nerolidol-Linalool Group (see Table 1).—Of the oils of seven trees of this group, six consisted almost entirely (*ca.* 90%) of (+)-nerolidol, minor constituents being benzaldehyde, sesquiterpenes and sesquiterpene alcohols, together with traces of alkali-soluble material. Linalool could not be detected in these six oils.

This oil corresponds to Baker and Smith's " *M. smithii* ", and the absence of linalool in their oils is thus confirmed. The remaining tree of this group, however (No. 28, Taree district), yielded an oil which in addition to the nerolidol contained a substantial quantity (*ca.* 30%) of (+)-linalool, and hence corresponds qualitatively with the nerolidol-linalool form cf Jones and Haenke, and referred to as Variety " A " by Penfold and Morrison in Guenther's " The Essential Oils " (1950). It would appear that citral and linalool monoxide are present only when linalool is a component of the oils of this group, since neither of these substances could be detected in oils consisting largely of nerolidol to the exclusion of linalool. They are possibly artefacts arising from aerial oxidation subsequent to the biosynthesis of the linalool in the plant. The presence of benzaldehyde, suspected by Baker and Smith, has been proven ; but it is almost certain that the cineole (up to 5%), limonene, dipentene and pinene found by them in association with nerolidol is due to their working on oils distilled from mixed foliage. Trees of the two forms were observed during this investigation to grow intermingled.

The Viridifloral-Cineole Group (see Table 2).—The remaining trees yielded oils distinguished by the presence of viridiflorol and cineole, together with all the compounds identified by Jones and Haenke (1938) in their cineole form (a single tree) growing near Brisbane. In addition, we have demonstrated the presence of traces of benzaldehyde. The present study indicates that the cineole and viridiflorol contents vary in an approximately inverse ratio : cineole was found from as little as 0·4%, ranging up to 38% ; corresponding viridiflorol contents ranging from something of the order of 27% down to about 1%. Such oils are similar to those referred to by Baker and Smith as being derived from their " *M. maideni* ". It is possible that the cineole content (45·6%) found by Jones and Haenke (*loc. cit.*), if determined directly on the crude oil by the Cocking method, is too high ; since the tables published for this cryoscopic method are valid only for mixtures of cineole and $C_{10}H_{16}$ hydrocarbons. The presence of more than traces of sesquiterpenes will result in a large positive error. However, occasional samples of oil from northern New South Wales and Queensland have been found in the past to have cineole contents of the order of 50–60%, i.e. similar to cajuput oil, and are referred to as the " Type " by Penfold and Morrison in Guenther's " The Essential Oils " (1950).

DISCUSSION.

Whilst differences in chemical composition among oils of the viridiflorol-cineole group merely mean a gradation of percentages of the same constituents, the same may not be true for the nerolidol-linalool group. A remarkable uniformity has been observed in the " 90% nerolidol " oils (Table 1), but should linalool accompany the nerolidol, it is then present in substantial amount. Furthermore, progeny of a naturally pollinated mother-tree of this latter type growing at Copmanhurst were found by Penfold, Morrison and McKern (1948) to yield oils of similar composition to that of the parent.

B

HELLYER AND McKERN.

TABLE 1.

Physico-chemical Data for Crude Oils of M. viridiflora, Nerolidol-linalool Form.

Tree No.	Locality.	Oil Yield, %	d_{15}^{15}	n_D^{20}	α_D	Solubility in 70% w/w Alcohol, Vols.	Acid No., mg. KOH per Gramme.	Ester No., mg. KOH per Gramme.	Nerolidol Content, %
1	Woy Woy	0.99	0.8895	1.4815	+10.75°	1.6	0.6	4.0	88.7
2	"	0.94	0.8862	1.4815	+11.45°	1.65	0.6	3.5	92.8
6	"	1.23	0.8866	1.4813	+12.00°	1.65	0.5	2.5	94.7
1	Taree	1.45	0.8845	1.4811	+12.10°	1.5	0.5	0.4	91.1
10	"	1.07	0.8851	1.4814	+10.90°	1.6	0.9	2.2	91.5
27	"	1.50	0.8851	1.4811	+12.40°	1.5	0.4	2.5	92.4
28	"	1.70	0.8808	1.4739	+14.05°	1.1	0.62	6.5	Not detd.; contains ca. 30% linalool.

TABLE 2.

Physico-chemical Data for Crude Oils of M. viridiflora, viridiflorol-cineole Form.

Tree No.	Locality (N.S.W.).	Oil Yield, %	d_{15}^{15}	n_D^{20}	α_D	Solubility in 70% w/w Alcohol, Vols.	Acid No., mg. KOH per Gramme.	Ester No., mg. KOH per Gramme.	Cineole Contents, %	Viridiflorol Content* (approx.), %
3	Woy Woy.	1.23	0.9435	1.4921	-4.15°	10	0.5	2.4	4.7	27
4	"	1.33	0.9432	1.4931	-3.65°	10	0.5	2.5	0.66	17
5	"	1.27	0.9450	1.4883	-4.10°	2.85	0.5	2.5	—	—
7	"	1.44	0.9357	1.4838	-2.00°	3.9	0.4	1.7	—	—
8	"	1.45	0.9307	1.4813	-3.82°	8.2	0.3	2.7	—	—
9	"	1.04	0.9485	1.4943	-3.35°	9.8	0.4	1.6	3.9	20
6A	Taree.	1.17	0.9594	1.4974	-1.00°	—	0.5	1.5	0.4	22
6B	"	1.08	0.9554	1.4973	-0.30°	3.5	0.6	1.4	4.8	19
7	"	0.75	0.9610	1.4990	+2.30°	—	0.4	1.2	18.4	1
8	"	1.50	0.9458	1.4909	+5.10°	—	0.4	12.2	38.0	10
9	"	1.73	0.9281	1.4773	-0.50°	1.6	0.4	6.0	—	—

* These figures are calculated from the actual weights of crude viridiflorol obtained from the oils by fractional distillation.

The relationship of the viridiflorol-cineole group to the Malaysian species yielding cajuput oil of commerce and to the New Caledonian " Niaouli " is of interest.   Both of these oils contain 50% to 65% of cineole, the remainder approximating somewhat closely in composition to the Australian oils (Guenther, 1950).   The New Caledonian tree is also referred to *M. viridiflora* Gaertn.

EXPERIMENTAL.

The crude oils were obtained by the steam-distillation of the fresh leaves and terminal branchlets, cut as for commercial distillation, and using tin-lined or glass apparatus.   The oils were dried with anhydrous sodium or magnesium sulphate prior to the determination of the analytical data shown in Tables 1 and 2.   Nerolidol contents were determined by the method of Glichitch (1923).   These figures are not strictly correct, since small quantities of other sesquiterpene alcohols are present.   Cineole was estimated by the method of Cocking (1920) on the terpene fractions (b.p. up to 60°–70°/10 mm.), and recalculated for the crude oils.

In general, the oil from each individual tree was fractionally distilled, and the nature of the principal constituents established for each.   Of the 11 viridiflorol-cineole oils, however, five were combined before fractional distillation after their similarity had been demonstrated from the analytical data.   In order to identify minor constituents, like fractions from different oils from within the same group were bulked for refractionation.

Melting points are uncorrected.

Nerolidol Group.—Typical fractional distillation data for the oil (100 ml.) of a single tree (No. 1, Woy Woy) are given in Table 3.

TABLE 3.

Fractional Distillation of 100 ml. of Oil of No. 1 Tree, Woy Woy.

Fraction.	Boiling Range, 10 mm.	Volume, ml.	d_{15}^{15}	n_D^{20}	α_D
1	112°–138°	6	0·8978	1·4858	+7·50°
2	138°–143°	10	0·8876	1·4818	+11·00°
3	143°–144°	10	0·8845	1·4815	+12·00°
4	144°	10	0·8843	1·4813	+12·50°
5	144°	10	0·8839	1·4812	+12·50°
6	144°	10	0·8837	1·4810	+12·50°
7	144°	10	0·8841	1·4813	+12·50°
8	144°	10	0·8847	1·4813	+12·50°
9	144°–145°	10	0·8859	1·4817	+12·20°
10	145°–146°	6	0·8882	1·4824	+11·30°
11	146°–163°	4	0·9055	1·4881	+5·20°
12	163°	2	—	—	—

Nerolidol.   Fraction 6 (4 g.) on oxidation with chromic acid as described by Ruzicka (1923) gave 3·2 ml. of oil from which was isolated a *fraction* 146°–148° and n_D^{20} 1·4935 which yielded a *semicarbazone* of m.p. 132°–133° from ethyl acetate.   Fraction 6 (2 ml.) likewise gave on prolonged standing (2 months) with phenyl isocyanate (2 ml.) and dry pyridine (0·5 ml.) a *phenylurethane* of m.p. 35°–37°.

Benzaldehyde.   The " first runnings " from the fractional distillation of the oils of two trees (Nos. 10 and 27, Taree) yielded an orange 2,4-*dinitrophenylhydrazone* of m.p. 240° which did not depress the m.p. of the 2,4-dinitrophenylhydrazone prepared from synthetic benzaldehyde.

Primary Alcohols.   By treating the still-pot residues from the fractional distillations with phthalic anhydride, the presence of small quantities of primary alcohols was demonstrated.

Linalool. This alcohol was established as a major component in only one oil, that of Tree No. 28, Taree. Although the greater portion of this oil was found to consist of (+)-nerolidol (b_5 130°–132° ; d_{15}^{15} 0·8816 ; n_D^{20} 1·4812 ; α_D +13·00°), 28% of the oil boiled at 80°–82° at 10 mm., and had d_{15}^{15} 0·8672 ; n_D^{20} 1·4626 ; α_D +18·15°. This *fraction* yielded a *phenylurethane*, m.p. 64°–65°, undepressed on admixture with the phenylurethane of a commercial sample of (+)-linalool from Bois de Rose oil.

Viridiflorol-Cineole Group.—Although considerable variations in the ratio of terpenes and cineole to sesquiterpenes and sesquiterpene alcohols occurred in the individual oils of this group, it will suffice to give data for one fractional distillation only (Table 4). This may be regarded as typical since this oil was a composite sample made by bulking the oils of trees Nos. 3, 5, 7, 8 and 9 from Woy Woy.

TABLE 4.

Fractional Distillation of 375 ml. of Oil of Viridiflorol-cineole Form.

Fraction.	Boiling Range, 5 mm.	Volume, ml.	d_{15}^{15}	n_D^{20}	α_D
1	30°–50°	145	(Not determin	ed prior to cineole	removal)
2	50°–85°	5	0·9266	1·4804	—6·00°
3	85°–88°	10	0·9372	1·4852	—3·60°
4	88°–110°	10	0·9290	1·4932	—4·80°
5	110°–112°	8	0·9223	1·5012	+0·60°
6	112°–120°	11	0·9305	1·5022	+9·60°
7	120°–129°	38	0·9618	1·5024	+11·00°
8	129°–132°	27			
9	132°–136°	85	Solidified on	standing.	
10	136°–144°	18			
Residue	144°	4			

Cineole. Fraction 1 (145 ml.) was thrice extracted with aqueous resorcinol solution (50%). The aqueous phase was steam-distilled with excess of sodium hydroxide solution to give a colourless *oil* (70 ml.) of characteristic odour, d_{15}^{15} 0·9156, n_D^{20} 1·4602. It gave an *o-cresol addition compound* of m.p. 56°, undepressed on admixture with the compound prepared from an authentic specimen of cineole. In the case of the oils of trees Nos. 4 and 6B, where the apparent cineole contents determined analytically were very low, particular care was taken to establish formally the presence of cineole by a similar procedure.

α-Pinene. After removal of the cineole, fraction 1 (55 ml.) was fractionally distilled at 10 mm. A fraction (23 ml.) was obtained which had b_{10} 39°–42° ; d_{15}^{15} 0·8654 ; n_D^{20} 1·4683 ; α_D +5·00°. It yielded a *nitrosochloride* of m.p. 110°, undepressed by admixture with a freshly-prepared specimen of α-pinene nitrosochloride of similar m.p.

(—)-*Limonene and Dipentene.* A further fraction (14 ml.) was obtained having b_{10} 53°–56° ; d_{15}^{15} 0·8618 ; n_D^{20} 1·4727 ; α_D —47·00°. Bromination in cold (*ca.* 0°) glacial acetic acid, followed by fractional crystallization of the precipitate, yielded *bromides* of m.p. 105° and 124°, undepressed on admixture with authentic specimens of the tetrabromides of limonene and dipentene respectively.

Benzaldehyde. Refractionation of lower-boiling fractions from all the oils of this group resulted in the isolation of a fraction yielding a 2,4-*dinitrophenylhydrazone* of m.p. 240°, undepressed on admixture with an authentic specimen of the derivative prepared from synthetic benzaldehyde.

α-Terpineol. Fraction 3 (1 g.), phenyl isocyanate (1 g.) and dry pyridine (0·5 ml.) were mixed and stood overnight. After mixing with water to destroy excess reagent, the *phenylurethane* was extracted with petrol. It melted at 111°–111·5° undepressed on admixture with

an authentic specimen of α-terpineol phenylurethane. Another portion of fraction 3 (3 g.) yielded a nitrosochloride of m.p. 120°–120·5°. A mixed m.p. determination with α-terpineol nitrosochloride showed no depression.

Viridiflorol. All higher-boiling fractions of oils of this group, together with their still-pot residues, solidified on standing to a buttery mass. (In some cases the crude oils solidified.) After pressing on porous tiles and recrystallization from *n*-hexane at −20°, the alcohol was obtained as white needles, m.p. 73°–75°. It failed to give a colouration with tetra-nitromethane. The melting point is higher than that of Jones and Haenke (1937), and is in agreement with that found by Davenport and Sutherland (private communication).

Found: C, 81·33, 81·29% ; H, 11·73, 11·61% ; O, 7·2, 7·5%. Calculated for $C_{15}H_{26}O$: C, 81·06% ; H, 11·77% ; O, 7·19%.

The *phenylurethane* (needles from methanol), prepared by the procedure of Davenport, Jones and Sutherland (1949), melted at 125·5°, not depressed on admixture with an authentic specimen.

Found: C, 77·90% ; H, 9·15% ; N, 4·11%. Calculated for $C_{22}H_{31}O_2N$: C, 77·45% ; H, 9·09% ; N, 4·10%.

Viridiflorol was dehydrated with formic acid (98–100%). The product (3·368 g.) was dehydrogenated for $2\frac{1}{4}$ hours at 180°–220° with sulphur (2·429 g.). The hexane-soluble material from the reaction mixture was chromatographed in hexane on alumina, resulting in the isolation of a deep blue viscous oil (0·688 g.) which yielded a 1,3,5-*trinitrobenzene derivative*, deep violet needles, m.p. 150°–151°, undepressed on admixture with a specimen of the 1,3,5-trinitrobenzene derivative of S-guaiazulene.

Sesquiterpenes. Fractions intermediate in boiling point between the α-terpineol and the viridiflorol were found to consist of dextro-rotatory sesquiterpenes also yielding azulenes on dehydrogenation. Their nature and relationship to viridiflorol are being investigated ; one sesquiterpene fraction resembling closely the product obtained from the dehydration of viridiflorol.

ACKNOWLEDGEMENTS.

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REGIONAL MAGNETIC SURVEY OF THE SOUTH SYDNEY BASIN.

By V. Bhaskara Rao, M.Sc.,
and H. Narain, Ph.D.

*Department of Geology and Geophysics,
University of Sydney.*

I. Introduction.

The Department of Geology and Geophysics of the Sydney University has undertaken to make thorough geophysical investigations of the Triassic Sydney Basin. The project envisages a close network of magnetic and gravity stations at one mile separation over the entire Basin in the first instance. This is, naturally, to extend over a number of years. Its first phase, however, has been completed with a magnetic and gravity survey of the southern half of the Basin. The magnetic investigations, their results and interpretation form the subject matter of this paper.

The geological importance of the Basin has been recognised for a number of years. The marginal areas of the Basin—especially those in the south, south-west, north and north-west—have proved their economic potential in the output of coal, mostly from the Upper Coal Measures of their Permo-carboniferous formations. There has been continuing interest in the oil and gas potentialities of the Basin and in recent years this has considerably increased. Geophysical studies on the Basin should provide valuable information particularly with regard to the basement and its structures, and may throw a considerable amount of light on the fundamental as well as applied geological problems of this region.

Regional magnetic work, similar to the present one. has not been attempted in New South Wales. However, several authors have carried out detailed magnetic surveys on selected areas for either academic or economic interests. The present investigation comprises an area of South Sydney Basin of about 1500 square miles with a total number 730 magnetic stations set up at a distance interval of approximately a mile. The magnetometer or the magnetic vertical force variometer used in the survey is of the Schmidt type made by Hilger and Watts.

The regional magnetic picture shows a marked high positive anomaly belt between a line drawn north-south through Cataract Dam and the coast east of this line. An equally pronounced positive high is obtained around the area in the vicinity of Mittagong and Bowral, while in the Burragorang Valley the anomalies have fallen to about −100 gammas. The area in between these two seems to be more or less " flat " magnetically except for a few pockets of isolated positive highs, and corresponds well with the shape of the basin.

Another interesting feature is the highly pronounced positive anomalies around the Robertson area, which from the surface indications must have been due to the outcrops of basalt in that area. There are two negative regions, one east and the other west of Moss Vale, whilst there is a positive anomaly region of about the same magnitude south of Moss Vale and north of Bundanoon.

From Robertson westwards, the undulating nature of the strata is clearly indicated in the regional picture.

Further south on the coast near Kiama the outcropping Jamberoo tuffs and Kiama tuffs do not seem to influence the magnetic results much, whereas Bombo basalts have shown themselves up on a few individual stations.

Correlation between the magnetic and gravity profiles on four geological sections in this area, has been attempted and the limitations discussed.

Susceptibility determinations made in the laboratory have been used to explain the magnetic anomalies in the field.

II. Plan and Procedure of Survey.

The present investigation comprises an area of about 1500 square miles. Though the Basin in the southern half itself extends over a much larger area a major portion of the area in which stations could not be set up, is mostly inaccessible by a motor vehicle. Almost all the roads and passable tracks were gone over and observations made along them. Stations were set up on the banks of the Avon, Cordeaux and Cataract Dams by traversing them in a motor launch.

Throughout the work one inch military maps were used to locate the station positions, except in the case of the work on the three dams mentioned above, for which accurate maps were made available by the courtesy of the Water Board.

The following precautions were observed while reading the Watt's magnetometer :

(i) The tripod stand was set up to approximately the same height each time from the ground.

(ii) Care was taken to see that there was no magnetic material on the person of the observer ; also the station positions were selected so that they were well away from interfering objects, such as wire fences, electric cables etc.

(iii) Extreme caution was exercised while lowering the moving magnet system on to the knife edges ; even slight jerks and jars are liable to damage the knife edges.

III. Corrections and Reduction of Field Data.

(a) Scale constant of Magnetometer.

The first step in the reduction of the field data is to convert the scale readings recorded in the field at various stations into vertical force values in units of gammas. The scale constant, i.e. the number of gamma units per division on the scale of the magnetometer, is usually given by the manufacturers ; but it is desirable to recalibrate the instrument at least once during every two months in the course of the survey.

Calibration of the magnetometer was carried out by the two well known methods of Helmholtz coils and the auxiliary magnets. As a result of a number of observations by both these methods a value of $30 \cdot 1$ gammas per scale division was adopted for the scale constant. Agreement between the scale constant values determined by the two methods was accepted as a verification of the given values of the magnetic moment of the magnets.

(b) Auxiliary magnet correction.

Whenever an auxiliary magnet is used to bring back the scale into the field of view of the telescopic system, a correction is applied for the extra magnetic field produced by the auxiliary magnet. From the difference in readings with

and without the magnet, the extra field produced by the auxiliary magnet was calculated.   This value of the extra field formed the correction term whenever the same magnet was used at the same distance.

(c) Temperature corrections.

The magnet system of the Watts magnetometer is temperature compensated, although a small correction factor of $-0 \cdot 5$ gamma per degree centigrade rise in temperature is given for accurate detailed surveys.   As the reading accuracy of the magnetometer used in these investigations was of the order of about 6 gammas, this correction has not been applied.   However, when auxiliary magnets are employed in the survey, correction for the change of their magnetic moments, and hence to the calculated fields produced by them due to the temperature changes, is applied.   This has been done by taking a set of observations at the Base at Prospect Hill at different temperatures and with auxiliary magnets.   After suitably correcting these observations for the diurnal variations at the Base, the remaining discrepancy in the observed vertical force values are attributed to the influence of the temperature changes on the magnetic moment.   Thus, for example, from a number of observations at the Base, a correction term of decrease in field by 4 gammas per degree centigrade rise in temperature was arrived at for the short magnet.

(d) Diurnal Correction.

From the distribution of stations at one mile intervals it can be seen that most of the time in a day's work is consumed in travelling from station to station. It was felt that returning to a local base station more than twice a day would considerably reduce the speed of work.   So, in most cases, the first station set up at the beginning of the day's work was reoccupied at the end of the day's work, thus getting an idea of the variation due to diurnal changes for the period of observations for that day.   This diurnal observed variation is distributed over the period of time of observations according to the pattern of diurnal variation in vertical intensity continuously recorded in the Commonwealth Magnetic Observatory at Toolangi, Victoria.   Also, on some days uniformly distributed through the period of observations, a continuous Askania vertical force recorder was run at the Prospect Base.   A comparison of records thus obtained with the Toolangi records showed a qualitative agreement with regard to the pattern of diurnal variation and justified the distribution of the amount of observed diurnal variation on the Toolangi pattern.

(e) Regional Correction.

This correction arises from the fact that the vertical intensity of the earth's magnetic field has a normal variation over the surface of the earth.   The correction is evaluated by reading off, in the first instance the gradients of vertical field intencity in the North-South and East-West directions for the whole area surveyed, from the Tables and maps published by the Carnegie Institute of Washington (1947), based on magnetic data recorded by various observatories distributed all over the world.   These gradients, given in terms of degrees latitude or longitude, are converted in terms of distances in miles.   For the area under consideration, average values of 13 gammas per mile in the North-South direction, and $2 \cdot 5$ gammas per mile in the East-West directions are adopted.

(f) Magnetic Anomalies.

The anomalies at stations are obtained by summing up algebraically the observed value of the vertical relative intensity at the station and all the corrections above mentioned, and calculating the difference between this sum

and the one for the Base at Prospect. All positive remainders are designated as the positive anomalies with respect to the Base, while negative remainders are called negative anomalies.

As seen in V, the basis for regional or normal correction is the assumption that the vertical intensity of the earth's magnetic field has a smooth variation over the surface. However, this assumption is only valid if, in the magnetic condition of the earth, there is a lateral homogeneity to a depth of at least a few tens of miles. The anomalies obtained as above, represent the departure from this condition and hence represent the irregularities in the horizontally homogeneous magnetisation of the earth's crust. These anomalies are explained in terms of probable distribution of magnetic material based on reasonable geological conditions. By this method of interpretation, inferences may be drawn as to the subsurface geology and crustal structures.

IV. Magnetic Studies and Their Interpretation.

Regional magnetic survey results, such as are reported in the present work, do not easily lend themselves to a precise interpretation in so far as they represent a composite effect of (1) surface and near surface geology, and (2) the basement structure and other deep seated bodies. However, in some cases, the correlation of the magnetic data in terms of the geology seems to be better than that of the gravitational data. This is partly due to the large effect of local changes in magnetic susceptibility on magnetic data and the comparative insensitivity of magnetic observations to other local factors such as elevation or density. The point can be best illustrated by calculating the relative gravity and magnetic effects. For example, a 16-feet change in elevation at a gravity station has the same gravitational effect of one milligal as 160-feet of material with a density contrast of about $0 \cdot 5$ gm./c.c., whereas a change of one or two percent of magnetite content of a rock formation is sufficient to produce a very considerable change in the magnetic readings.

Just as gravity anomalies are due to variations in density, the magnetic anomalies can be attributed to variations in magnetic polarization. Polarization refers to the strength of magnetic field present and is the sum of induced polarization due to the present field of the earth and permanent polarization inherent in the material and varies with the magnetic susceptibility of the various rocks.

The magnetic polarization of sediments is usually negligible as compared to that of the igneous rocks. Therefore the magnetic anomalies, in general, primarily reflect the configuration of the underlying igneous rocks and variations in their magnetic susceptibility. Exceptionally high values, must represent rocks with extraordinary concentrations of minerals of high magnetic susceptibility, such as magnetite and ilmenite.

In the case of four sections discussed separately the regional magnetic anomaly has been arbitrarily obtained by the smoothing of profiles. This procedure has been, at times, counter-checked by observing the average anomaly around a station to a reasonable distance. These regional anomalies are discussed in relation to the known trends of geological beds, and, wherever reasonable, these discussions have been extended to a consideration of the basement and its structure. An interpretation of the residual anomalies on these sections has been attempted in terms of surface and near surface lithology. Individual stations, where the anomalies might be of a special interest, have been discussed suitably in their proper places.

The Base station for regional magnetic surveys reported here is established at Prospect Hill, nearly 20 miles west of Sydney. It is situated on Wianamatta shales to the north of the main intrusion. Though not centrally located,

this was chosen as the Base because the vertical intensity value here was recorded a number of times and established arbitrarily as 1160 gammas during the course of a detailed magnetic and gravity survey undertaken on the Prospect intrusion by Narain. Magnetic anomalies of all the stations have been calculated with respect to this Base.
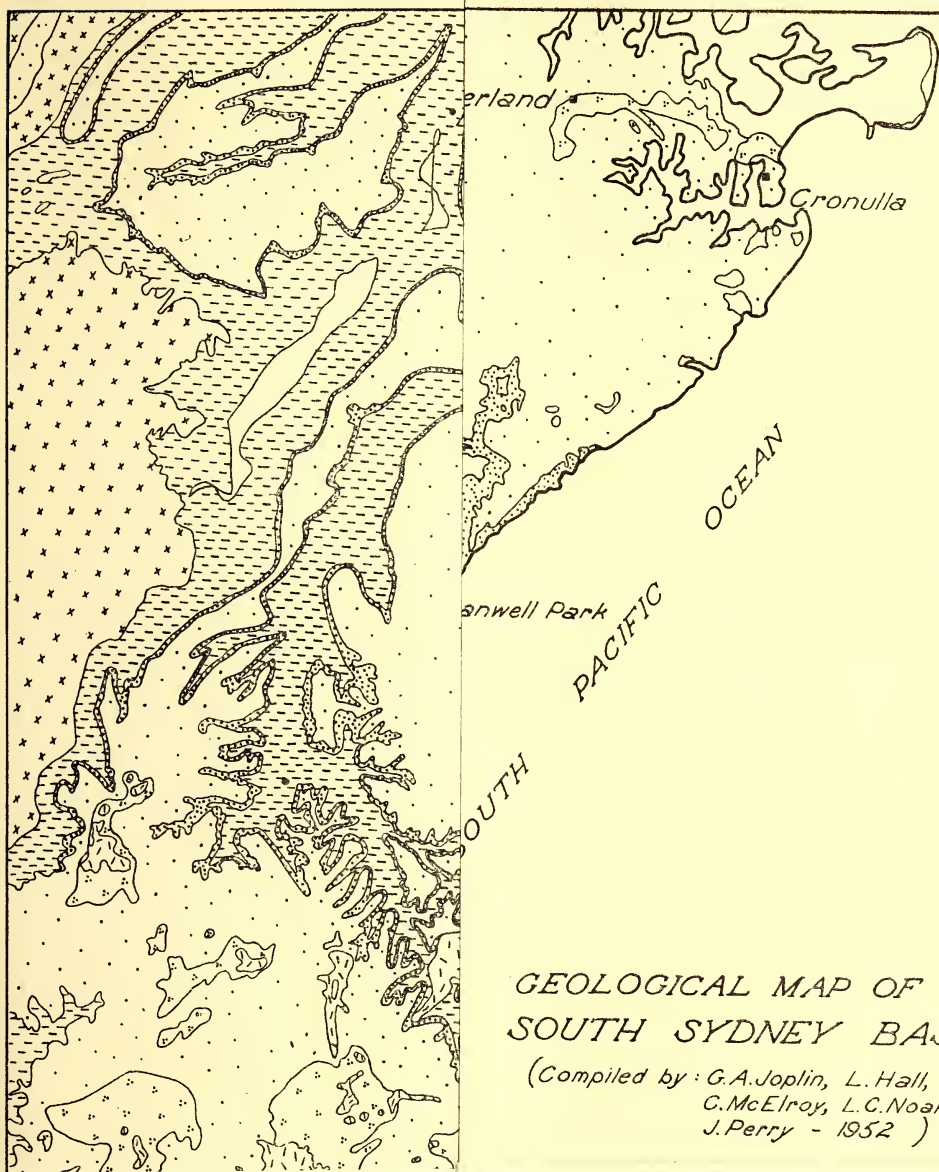
V. RESULTS OF THE SURVEY.
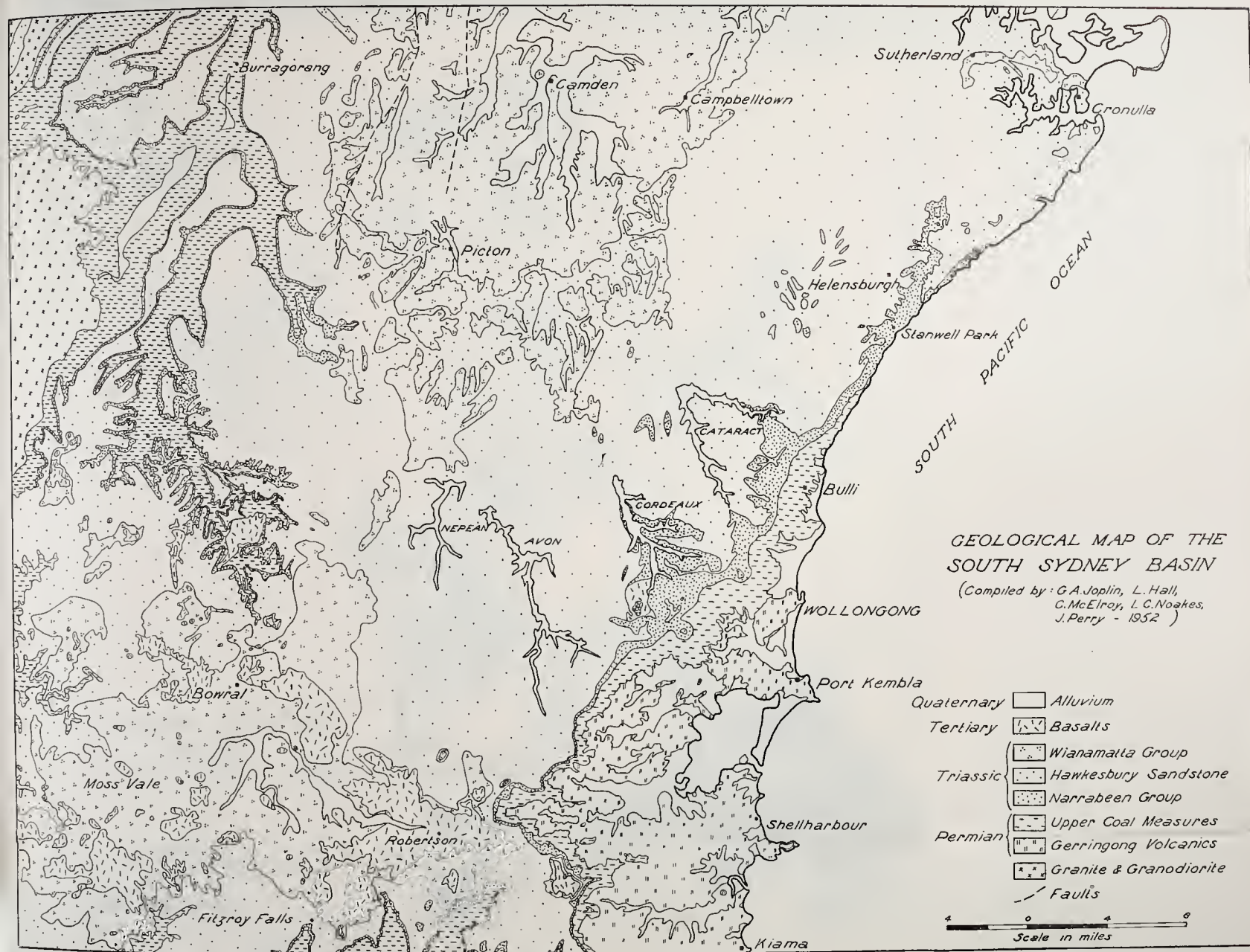
(a) *Discussion of Regional Survey.*

A generalised regional geological map of the greater portion of the area of the Basin covered under the present magnetic survey as compiled by the Bureau of Mineral Resources, Geology and Geophysics, under the direction of the Commonwealth Department of National Development, is shown in Fig. 1. This covers the area within the limits of a little north from Camden to Kiama and Robertson in the south, and from about Burragorang Valley in the west to the east coast. This shows clearly the Permo-Triassic nature of the basin. Surface geology indicates formations mostly ranging from Quarternary to Permian. The Quarternary formations, which consist of alluvium, gravel and swamp deposits, are mostly found on the coastal regions. Rocks of the Tertiary period are mainly basalt and basanites, volcanic agglomerates and breccias, dolerites and tinguites. These occur in pockets spread in the southern and south-western portions of the basin, the largest of them being the basaltic area at Robertson. Other places, where these outcrop, are near Mittagong, Moss-Vale-Bowral area and Exter-Sutton Forest area. Cordeaux Crinanite occurs in a small patch south-west of the Cordeaux Reservoir. The rest of the area is almost covered by Triassic and Permian formations. The Triassic is represented by the Wianamatta group of shales and sandstones, the Hawkesbury group of sandstones and the Narrabeen group of sandstones, shales and greywacke. Permians are represented by the Illawarra or Upper Coal Measures containing shale, chert and sandstone with coal seams, Gerringong volcanics or the Upper Marine Series, mostly in the coastal districts from Wollongong down south to Kiama, which are composed chiefly of tuffs and tuffaceous sandstone with flows and sills of latite.

Fig. 2 shows the magnetic anomalies obtained in the basin, together with the Stations established and their numbers. ABC, DE, FG and HI are four section lines along which the gravity and magnetic profiles have been discussed later.

The regional magnetic anomaly picture indicates a fair agreement with the general structure of the South Sydney Basin as outlined by the structure contours drawn at base of Wianamatta and at the top of Coal Measures (Willan, 1925).

Broadly speaking, anomalies ranging between $+100$ and $+200$ gammas seem to be typical of the Basin area. Nearly all the area between two north-south lines—one drawn a little west of Cataract Reservoir and the other a little west of Picton—is enclosed by such anomalies. On either side of these lines the anomalies show a tendency to increase, thereby bringing the trough-like nature of the basin into clear relief. In this area, there are a number of small pockets of anomalies less than $+100$ gammas. This is thought to be due to the varying thickness of sediments of the Wianamatta stage of the Triassic. In the Campbelltown district, where the Wianamatta stage has a maximun thickness of about 700 feet of grit and sandstones the anomalies are lower than in places where the other series of the Triassic outcrop. But these are only local features, which do not substantially alter the trough-like picture of the basin. Nearer the coast the anomalies rise up to the range of $+200$ to $+400$ gammas enclosed by the 200 and 300 gamma contours. This increase in anomalies—especially in the National Park and Stanwell Park regions—is believed to be due to the outcrops of the Narrabeen group of rocks. Narrabeen sandstones,
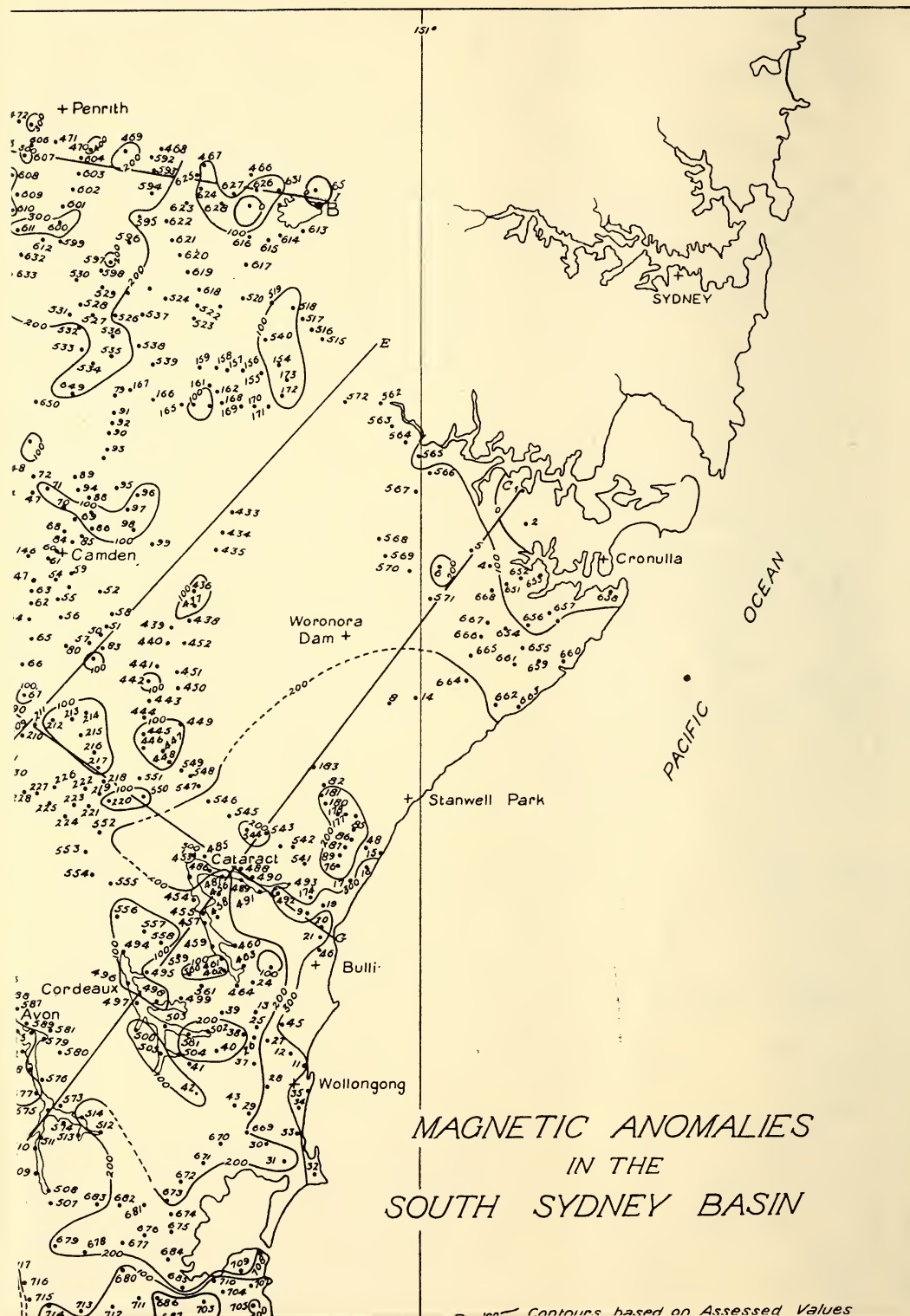
GEOLOGICAL MAP OF THE
SOUTH SYDNEY BASIN

(Compiled by : G.A.Joplin, L.Hall,
C.McElroy, L.C.Noakes,
J.Perry - 1952)

GEOLOGICAL MAP OF THE
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Quaternary	Alluvium
Tertiary	Basalts
Triassic	Wianamatta Group
	Hawkesbury Sandstone
	Narrabeen Group
Permian	Upper Coal Measures
	Gerringong Volcanics
	Granite & Granodiorite
	Faults

Scale in miles

Text-fig. 1.

MAGNETIC ANOMALIES
IN THE
SOUTH SYDNEY BASIN

⌢‒‒₁₀₀⌢ Contours based on Assessed Values
⌣‒‒₁₀₀⌣ Contours Extrapolated
  •   Magnetic Stations

Miles

Text-fig. 2.

+ Penrith

SYDNEY

Camden

Woronora Dam +

Cronulla

PACIFIC OCEAN

+ Stanwell Park

Cataract

+ Bulli

Cordeaux

Avon

Wollongong

MAGNETIC ANOMALIES
IN THE
SOUTH SYDNEY BASIN

Contours based on Assessed Values

in places, contain highly ferruginous bands and the chocolate coloured shales of this group decidedly contain more ferrunginous material than the average shales.   Analyses of chocolate shale yield as much as 15 to 16 percent of Ferric oxide.   Further down south, in the region of Bulli and Wollongong districts, the anomalies may be due to numerous lavas and tuffs.   These have a maximum thickness of about 1,000 feet in the neighbourhood of Kiama.   There are a number of minor dykes in the south coast region.   One of these systems is in an area north-west of Bulli Pass.   Though, in fact, the whole dyke system of the basin could not be clearly established by a regional survey of this type, it might be possible to explain some of the individual stations by correlating them with known dykes or other intrusions.   In the Bulli region, the anomalies at stations 9, 492, 490, 545 and 546 seem to confirm the general trend of the group of dykes in this region.   It must also be emphasised that the spacing of the stations is too wide to facilitate picking up of minor features.   For example, the small pocket of Cordeaux Crinanite west of the Cordeaux reservoir lies within a $+100$ gamma contour.   A number of stations on the Gerringong volcanics on the western side of Lake Illawarra have anomalies of the order of $+250$ gammas.   However, there is considerable variation of anomalies on this series further south to Kiama.

Another interesting feature in the regional picture is the positive high anomaly region around Robertson.   The anomalies here range from $+100$ to $+800$ gammas and are due to the basaltic flow surrounding the Robertson area.   A detailed discussion of this area will be undertaken at a later stage.   For regional considerations, it may be stated that the anomalies cover well the area of this basaltic flow and indicate, further, that the flow may be extended in the north to more than a mile from the present mapped area.   It is interesting to see that, somehow, the same type of flows in the vicinity of south-east of Mittagong and Exeter area do not produce such high anomalies.   However, the region west of Robertson, north of Bundanoon and south of Mittagong is magnetically quite a disturbed area.   Some of the highly anomalous stations with anomalies ranging between -800 and $+1400$ occur in this region.   This may be due to the number of basaltic intrusions coming up and due to reversal of polarisation in certain areas.   Four stations, 360, 361, 362 and 363, near Mittagong have anomalies of $+750$, -340, -790 and $+140$ respectively.   Previous work by Booth on the Mt. Gibraltar shows very high positive and negative anomalies.   All these anomalies may be correlated with the same basaltic flow, perhaps, which is spread over many areas in the district.   The fact that some of these high positive anomalies occur isolated on the tops of hills may indicate that there are, throughout the area, cappings of these basaltic flows left on the top of these hills.

On the western and eastern sides of the Exeter-Bundanoon positive high, we get two areas of negative anomalies, which go down from -100 to -200 gammas.   This perhaps indicates more a thinning of the igneous flows in this region or possibly a regional reversal in polarisation than any significant changes in the structure of the basement.   The major part of the anomalies in this region must be attributed to surface and near surface effects.

From about Luddenham to Penrith in the north and Rooty Hill in the north-west, the anomalies are again high and positive.   The surface geology indicates a number of dykes and a few volcanic necks two of which occur at Erskine Trig station and Rooty Hill respectively.   These perhaps are the cause for small isolated pockets of 300 gamma and 200 gamma contours.   In the regional picture, whether the positive high spread over an area is due to a subsurface structure of considerable extent cannot be established from surface indications.   This aspect has been further discussed where section HI is considered.

(b) *Magnetic and Gravity Profiles.*

Two of the four sections shown—ABC and DE—run roughly in south-west to north-east directions. These are 55 and 62 miles long respectively and nearly cut across the entire length of the area covered by the survey. The other two sections—FG and HI—are roughly in the north-west, south-east direction. These sections are reproduced from the map accompanying Harper's
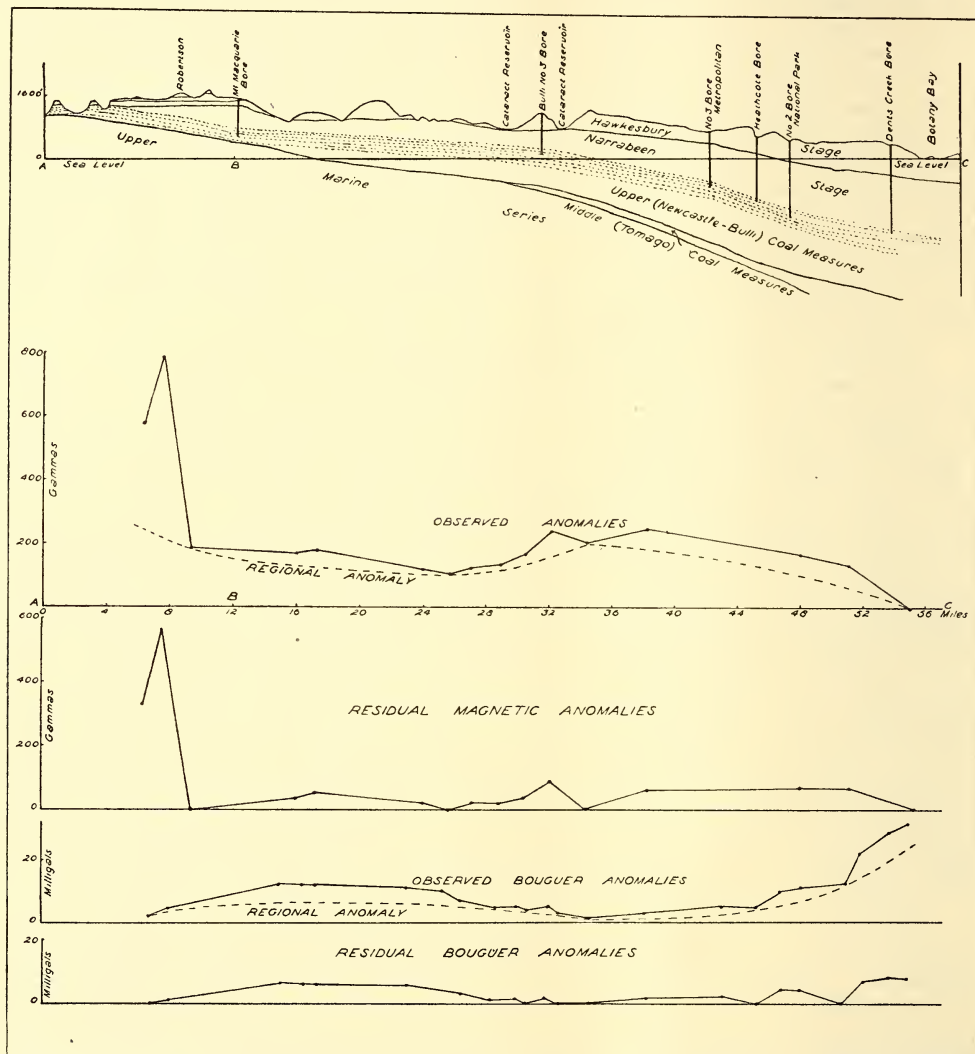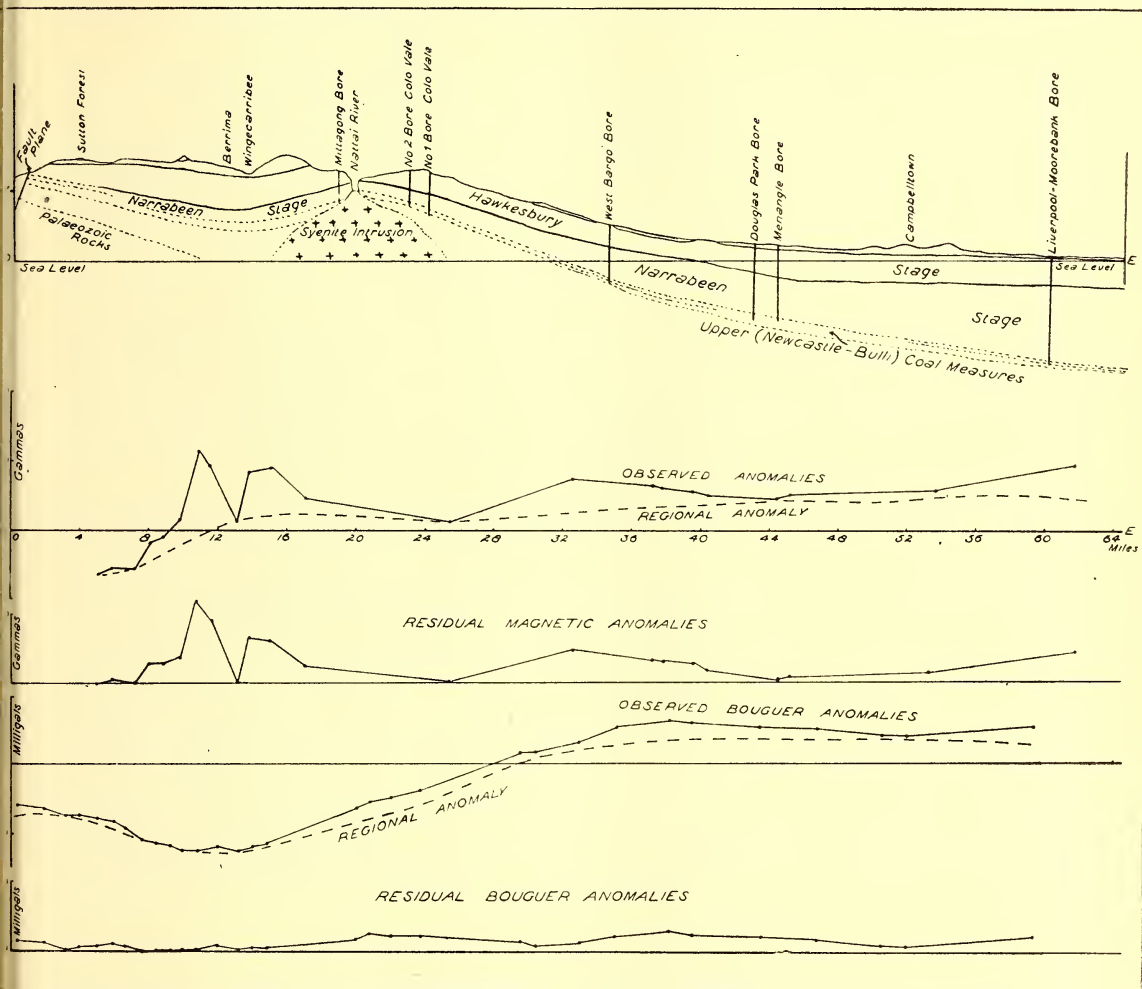

Text-fig. 3.—Geological section and profile of magnetic and gravitational traverse between Robertson and Botany Bay.

report (1924). Since publication of these sections, certain changes were made in the geological terminology. However, for the purposes of discussion here the old terminology has been retained.

(i) *Section ABC.*—This section (Fig. 3) extends from Robertson to Botany Bay and cuts across a number of bores, the deepest of which are the No. 2 National Park Bore and the Dent's Creek Bore. Starting from the Bulli No. 3 bore, where the coal measures are at a depth of 1,000 feet, the beds start sinking

down until at Dent's Creek Bore they are at a depth of over 2,200 feet.   From
the trend of the beds, a part of the trough of the basin could be seen.   The
regional anomalies reflected in the gravity and magnetic profiles show opposite
trends, a trough in the gravity and a corresponding bump in the magnetic.
However, the residual gravity and magnetic anomalies follow more or less the
same trend, though in the case of residual magnetic anomalies the variations
are more pronounced, indicating that magnetic data are more sensitive to

Text-fig. 4.—Geological section and profile of magnetic and gravitational traverse between
Sutton Forest and Liverpool.

surface and near surface changes in geology than the gravity data.   This is
shown more clearly by the anomalies around the Robertson area, where the
residual magnetic anomaly is more pronounced than the gravity anomaly.
Whether the regional high in the magnetic profile beyond No. 3 Metropolitan
bore is due to the increased thickness of the Narrabeens or to some uplifting
of the basement cannot be established at this stage.

(ii) *Section DE*.—This section, shown in Fig. 4, runs from Sutton Forest
through Berrima, Nattai River, West Bargo, Campbelltown and up to Liverpool.

Starting with negative values a little north-east of Sutton Forest, the regional magnetic anomalies rise gradually to positive values in the Berrima region,
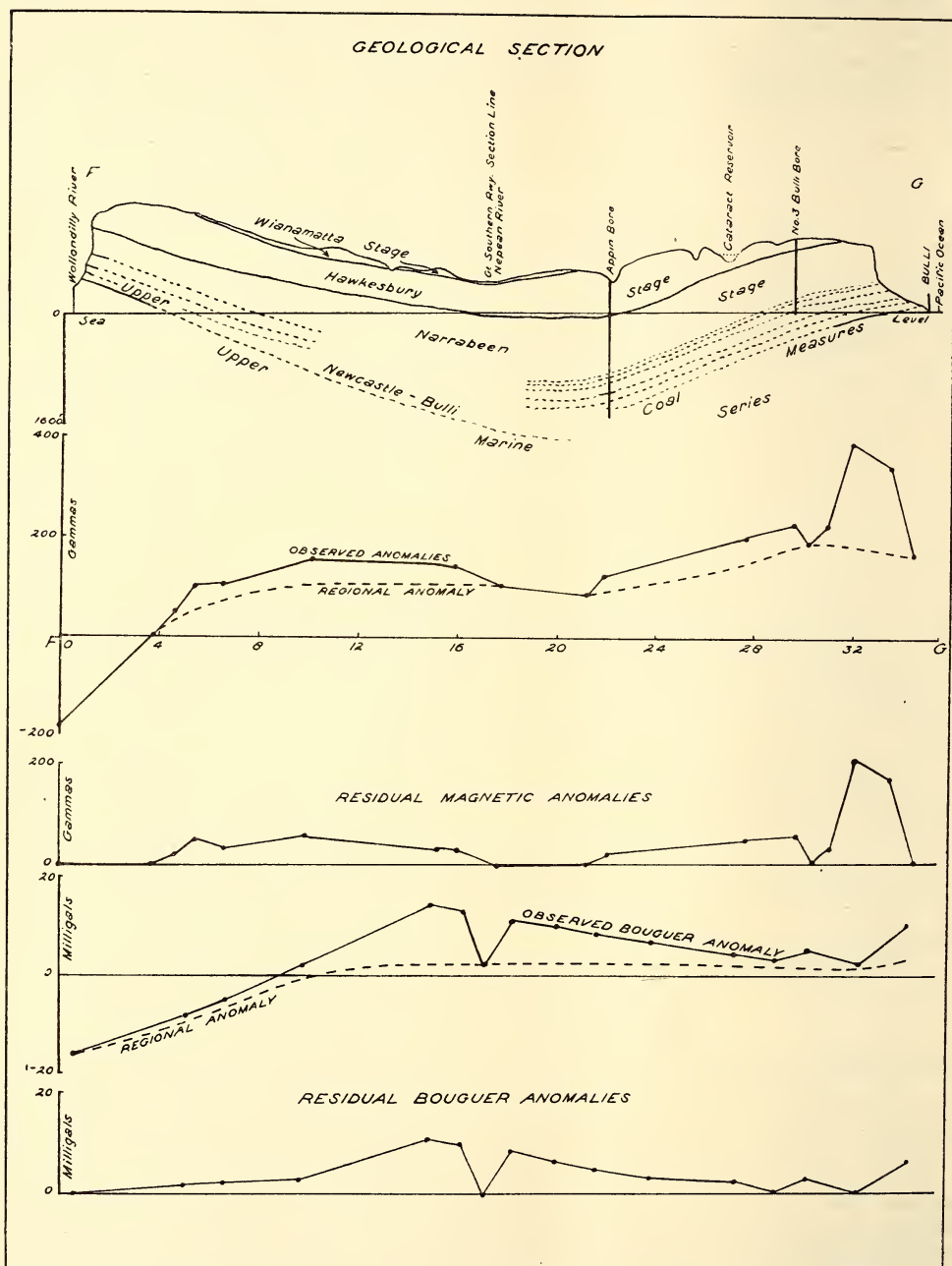
Text-fig. 5.—Geological section and profile of magnetic and gravitational traverse between Wollondilly River and Bulli.

from where on they remain positive and show little variation. There does not seem to be any agreement between the gravity and magnetic regional profiles ;

whereas in the residual anomaly profiles both gravity and magnetic anomalies are positive throughout.   The Syenite intrusion, which outcrops in the Nattai River, as can be expected, has no considerable effect on the magnetic regional or residual anomalies.   Actually it is suspected that the removal of the Narrabeens by the acidic intrusion of Syenite is responsible for the fall in the residual magnetic anomalies in this region, which seem to rise on either side of the intrusion.   The density contrast between this Syenite intrusion and the neighbouring beds of the Hawkesbury and Narrabeen stages is not large enough to be clearly reflected in the residual gravity profile.

(iii) *Section FG.*—As shown in Fig. 5 this section extends from Wollondilly River in the Burragorang region in the west to Bulli on the east coast and cuts across the basin area.   Both the gravity and magnetic regional profiles fail to reflect the basin structure in any striking manner.   The gravity anomalies starting with negative values in the Burragorang region become positive at about 10 miles east and remain more or less constant thereafter ;   while the regional magnetic anomalies show a tendency to increase on either end, with a faintly perceptible trough in the middle which roughly corresponds to the trough of the basin.   A persistent positive magnetic high of the order of 200 gammas just east of No. 3 Bulli bore, both in this and in Fig. 3, in the residual anomaly indicates that it is of local origin.   This section again raises doubts as to the extent of the reliance that can be placed on a regional survey of this type to clearly delineate the basement structure.   Unless many more stations are established in the region any interpretation beyond bringing out broad general features will be of doubtful significance.

(iv) *Section HI.*—This runs from the Nepean River (Fig. 6) in the west almost to the base at Prospect and lies in the deep trough area of the basin. The section is, perhaps, an over-simplification of the underground features.

The regional magnetic profile shows a marked peak of about +300 gammas around the Penrith-Rooty Hill area ;   while the regional gravity peak is less pronounced, though broader in extent and fairly high in magnitude (+20 milligals).   On the assumption that the residual anomaly peak in this region is produced by a single magnetic pole and using the Tiberg depth rule that the horizontal distance from a point directly over the pole to a point where the anomaly falls to half its maximum value is equal to $\frac{3}{4}$ times the depth of the pole, a depth of about 5,600 feet is obtained.   However, it must be appreciated that in such calculations a closer network of stations is needed to be able to obtain a valid average for the regional effect.   The highly fluctuating residual magnetic profile is believed to be due to a number of small dykes and similar intrusions traversed in this region.   Residual gravity is fairly uniform and flat.
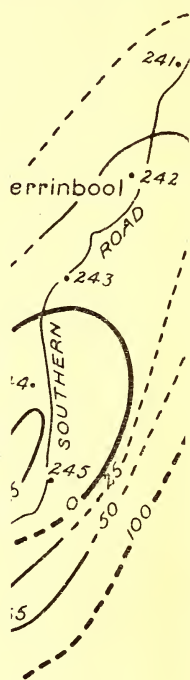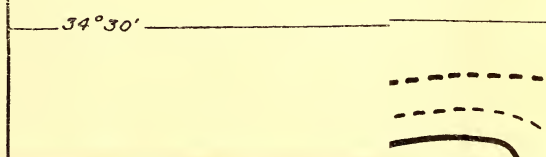
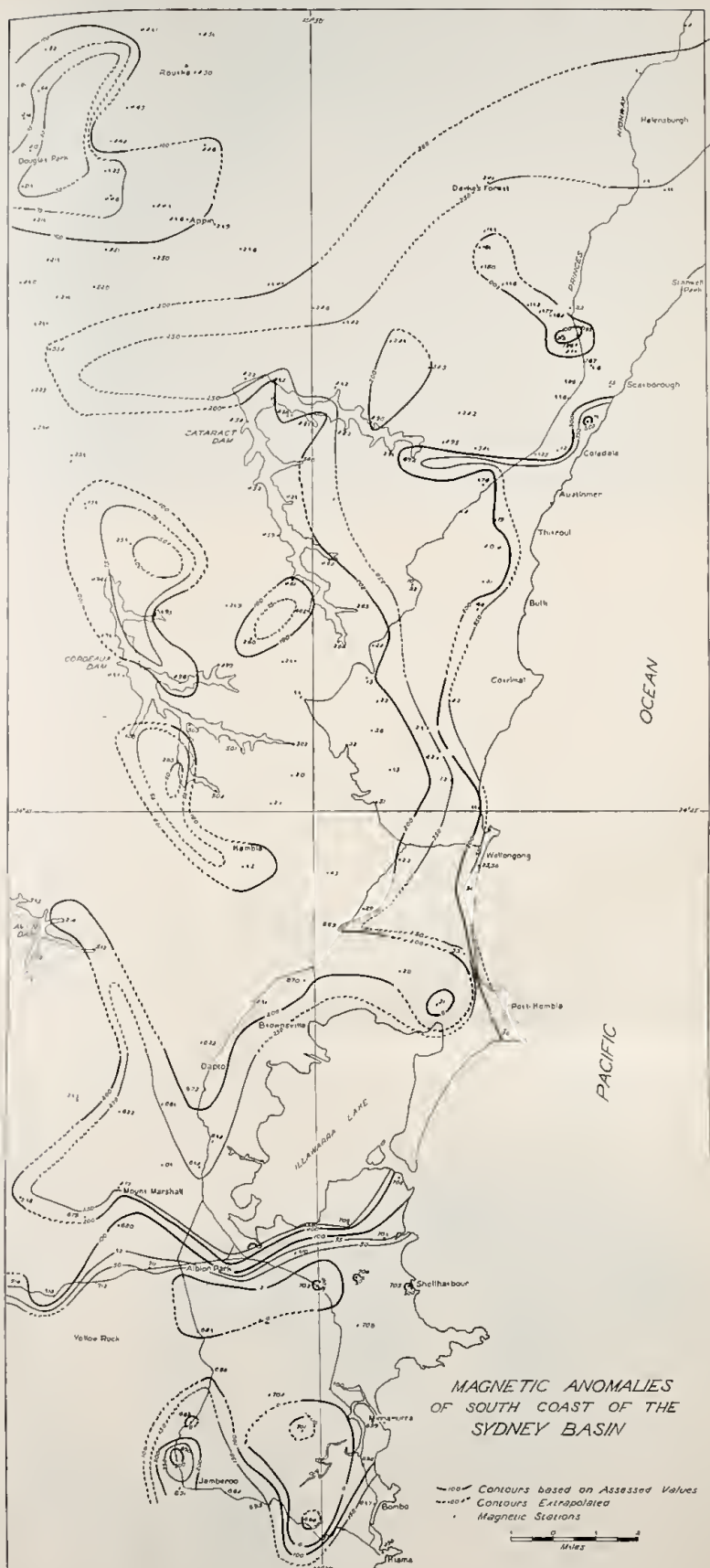*(c) Detailed Discussion of South-Coast Area.*

The isoanomaly map of the South Coast region and its vicinity is shown in Fig. 7.

The magnetic anomaly contours on the coast show a rise and indicate, generally, the trend of beds coming up.   The +200 gamma starting from about Helensburgh passes right down the coast nearly to Shellharbour in the south. As we traverse nearer the coast the anomalies increase up to +350 and +400 gammas.   In the northern region up to Stanwell Park the anomalies may be attributed to the outcropping Narrabeens ;   whereas south of Stanwell Park these must in a large measure be due to the numerous latitic flows.   In general, the extent of these high anomalies agrees with the pattern of distribution of these flows and sills.   Tracing the actual direction and extent of these individual dykes and sills is an important problem, as these igneous intrusions are the
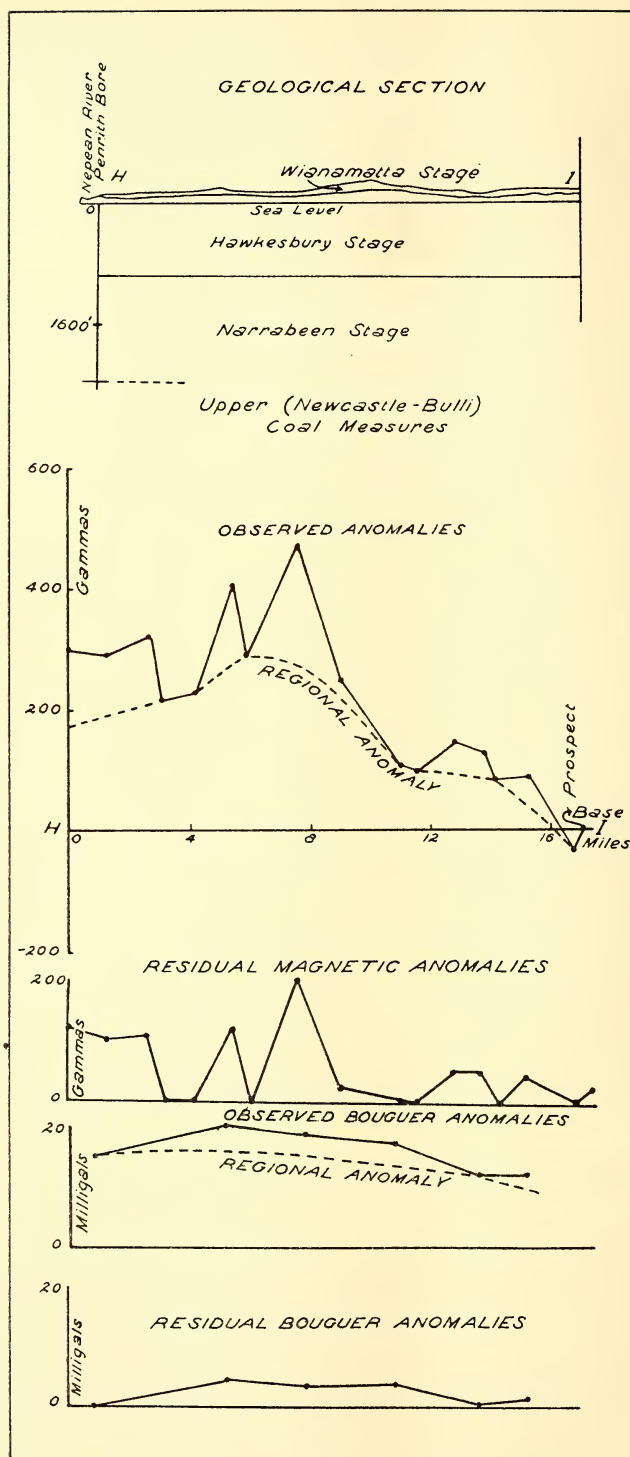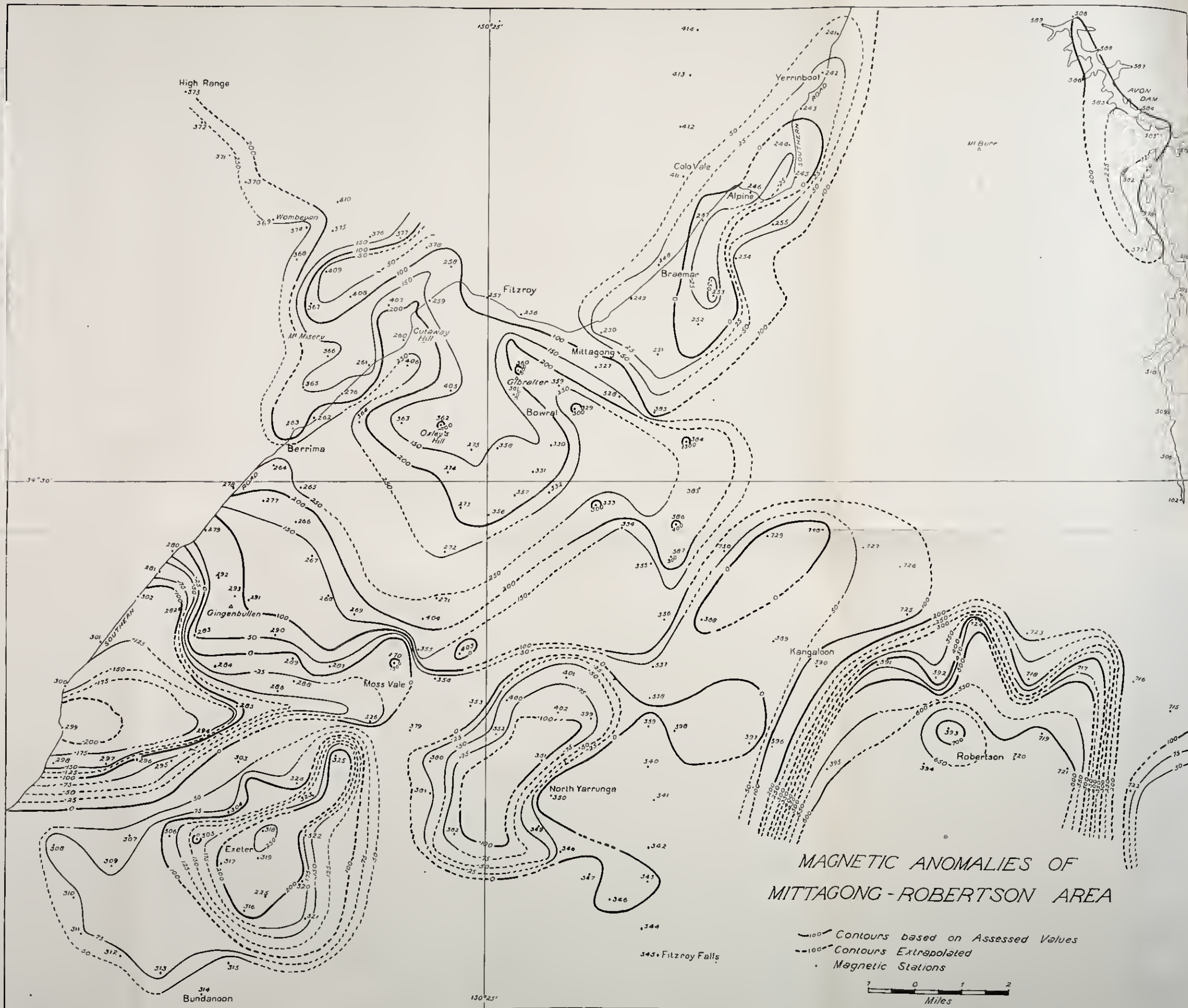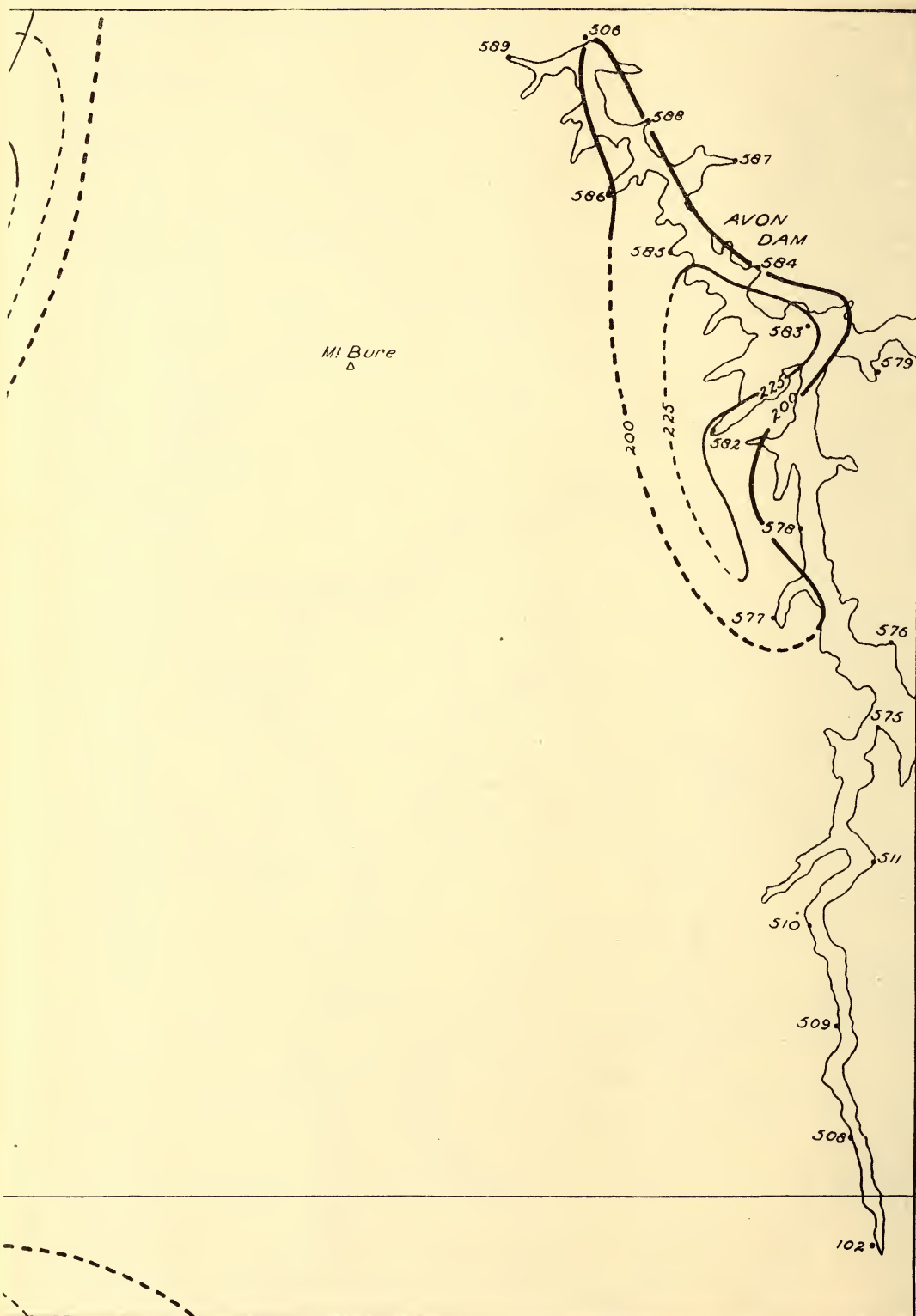
Text-fig. 6.—Geological section and profile of magnetic and gravitational traverse between Nepean River and Prospect Hill.

errinbool •242

ROAD

•243

SOUTHERN

•245

25

50

100

•362

•361

•380

•379

•326

Moss Vale

•354

500

270

•355

•404

•269

•271

•272

34°30'

MAGNETIC ANOMALIES
OF SOUTH COAST OF THE
SYDNEY BASIN

Contours based on Assessed Values
Contours Extrapolated
• Magnetic Stations

Text-fig. 7.

MAGNETIC ANOMALIES OF
MITTAGONG - ROBERTSON AREA

———₁₀₀— Contours based on Assessed Values
---₁₀₀--- Contours Extrapolated
  •   Magnetic Stations

Miles

Text-fig. 8.

cause of coal cindering and, in some cases, the source of major difficulties in mine planning and development.

In the area covered by Kiama, Jamberoo, Albion Park and Shellharbour, there is considerable variation of anomalies. Stations 685 and 686, about a mile apart in the Albion Park area give anomalies of +220 and −8 gammas respectively. Stations 686, 687 and 703 cover a fairly large area of zero anomaly ; this possibly is due to the thick cover of alluvium present in this area. Station 696, near the Kiama lighthouse, has a high positive anomaly of 812 gammas. This station lies entirely on the Blow Hole lava rocks, which contain as much as 7·0 per cent. of magnetite. High anomalies in the neighbourhood of Kiama are due to the Kiama tuffs, and the trend of these anomalies agrees well with the apparent north-west dip of these tuffs in the region.

In the vicinity of Kiama and Bombo quarries a marked columnar structure is seen ; the columns range from three to eight feet in diameter. When fresh, these rocks have a basaltic appearance. The coarsely crystalline representative rocks of this magma show a resemblance to some of the Essexite samples of the Prospect area. Anomalies at stations 696, 697 and 699, near Kiama, Bombo and Minnamurra, gradually decrease from about +800 to +100 gammas. Stations 693, 694, 695, 696, 697 and 698 have anomalies of +153, −388, +137, +812, +477 and +96 respectively. This variation gives an idea of the highy disturbed nature of the region as a result of the various flows cutting across the country here.

(d) Detailed Discussion of Mittagong-Robertson Area.

The area covered in this discussion is bounded by Yerrinbool in the north Robertson in the east, the Hume Highway in the west and Bundanoon in the south. Magnetic contours, drawn at intervals of 25 gammas, wherever possible, in this area, are shown in Fig. 8. Particular attention has been paid in this discussion to the Robertson district.

The magnetic anomaly clearly shows the highly disturbed nature of the area. Fairly large areas are covered with high positive and negative anomalies. In the Colo Vale-Braemar-Alpine region, north of Mittagong, the anomalies are small, though their variation is well defined. From Colo Vale to Alpine, the anomalies change from +50 gammas to −25 gammas and then start increasing further east. The shape of the area included by these anomalies points to some sort of a minor trough in this region. Another minor feature is the +200 gamma contour enveloping the northern half of the Avon Dam.

Most striking of the anomalies shown in Figure 8 is the saddle-shaped high anomaly region around Robertson. This is due to the basaltic flow in this region. Coverage of these anomalies agrees well with the known extent of the flow. A section from a little west of Kangaloon passing through a little north of Robertson to Hoddle's Hill in the south-east, shows a variation from nearly 500 feet to 50 feet in the thickness of the basaltic flow. For station 721 on Hoddle's Hill, where the thickness of basalt is about 400 feet, the anomaly is +630 gammas ; while station 722, which falls outside the sheet of basalt, has an anomaly of +70 gammas only.

Starting about three miles south of Berrima, there is a negative anomaly region for nearly six miles. This extends on the east up to Moss Vale. Stations 287 and 288, which lie on either side of the Blake's Hill intrusion, have anomalies of +54 and −29 gammas respectively. The area of these negative anomalies is mainly covered with Wianamatta shales, though there are a few intrusions coming up in certain parts. Station 285 which lies about half a mile south-west of the intrusion near Government House, has an anomaly of −110 gammas ;

s

station 325, near Mount Broughton intrusion, has a positive anomaly of +230
gammas ; while station 305, which lies on basalt at the Sutton Forest Trig.
station, has a negative anomaly of —80 gammas.   In the Exeter-Sutton Forest
area there is a high positive anomaly region with anomalies going up to +250
gammas ; further east, up to North Yarrunga, this is followed by another negative
anomaly region with anomalies down to —100 gammas.   This succession of
positive and negative anomaly regions points to an undulating set of beds
in this area ; there might be a minor uplift in the positive anomaly area.

North of Berrima, a large area covering High Range in the north-west,
Mittagong in the north-east and Moss Vale in the south, is enclosed by positive
anomalies which decrease from +250 gammas in the south to +50 gammas in
the north.   This area includes Mount Gibraltar, Cutaway Hill and Oxley Hill.
In the " Gib " region Booth has observed various pockets of negative anomalies.
Station 359, half-way up to the Gib, station 360 on the top of the Gib, and station
361 on the other side of the Gib, have anomalies of +230, +750 and —340
respectively, which shows the wide range of anomalies obtained in short distances
in this district.   On the crest of Oxley Hill is station 362 with an anomaly of
—800 gammas.   Again, station 270, which is in a paddock near Moss Vale
has an anomaly of —500 gammas.   It was observed in this paddock that
anomalies changed from —500 to +500 gammas in a short distance of 50 yards.
These sudden variations of positive and negative anomalies in the district
lead one to suspect that some of these flows might have reverse polarisation.
Stations 270 and 362 are strong pointers in this regard.   But unless a detailed
magnetometric survey, with a close network of stations spaced perhaps at intervals
of 20 to 30 feet, is carried out on such localities, it would not be possible to trace
their extent any further.   However, it may be pointed out that there are
a number of small areas suitable for such detailed magnetometric work in
the district.

VI. Correlation of Laboratory and Field Observations.

In the laboratory the authors have determined magnetic susceptibilities of
a number of rock specimens from Prospect Hill and from other regions of the
South Sydney Basin.   The design and construction of the apparatus, the
method of operation, and the results of susceptibility determinations and their
discussion form the subject matter of a separate paper.   However, a short
account of the susceptibilities of various rocks of the basin and the anomalies
is included here.   Susceptibility values mentioned here are those measured
at a field of 44 oersteds, and the anomaly values are those nearest to the place
from where the rock is obtained.   Where there is no station near enough to
a place, an average value for a few stations in the vicinity is quoted.

Generally speaking, the magnetic anomalies increase in areas where rocks
of high susceptibility occur.   Thus susceptibility values of 3,000 to 5,000 $\times 10^{-6}$,
c.g.s. produce anomalies of the order of +200 gammas, while anomalies of
+300 to +400 gammas are produced in areas where rocks of susceptibility
8,000 to 10,000 $\times 10^{-6}$ c.g.s. occur.   A number of discrepancies, however, could
be cited.   Thus, for example, a Robertson basalt yielded a susceptibility value
of only 3,000 $\times 10^{-6}$, while the anomalies in that area rise up to +600 gammas.

It may be pointed out that (i) the small number of samples studied
for susceptibility from any single formation, (ii) the enormous variation of
susceptibility among same types of rock from the same formation, (iii) the high
field at which the susceptibility values are measured, and (iv) the lack of a
large number of magnetometric observations on the same rock formations,
are some of the factors which vitiate any attempts at quantitative correlation
of the susceptibility with the magnetic anomaly.

VII. Conclusions.

In conclusion, the results of the survey may be stated as :

1. An area of nearly 1,500 square miles in the southern part of Sydney Basin has been covered with 730 magnetic stations on a regional basis.

2. A magnetically flat area has indicated the broad outline of the basin.

3. A detailed discussion of two areas, with interesting anomalies, has shown that various lava flows have been reflected in the regional picture.   The survey, in addition to providing valuable information with regard to magnetic variations in the basin area, has indicated several areas of interest, where close detailed work may be undertaken.

4. Attempts to correlate the regional magnetic picture with the structure contours on different formations have revealed general agreement with the structure of the basin.

5. Correlation between magnetic and gravity profiles on four geological sections has shown that the degree, to which the lithological and structural changes are reflected, depends on the variations of magnetic susceptibility and density.   The apparent disagreement between the profiles in some cases is believed to be due to the ambiguity involved in the interpretation of the data and the differences in the amount of ground control obtainable in the two methods.

6. Susceptibility determinations made in the laboratory have been applied to explain the magnetic anomalies in the field.   This was achieved with a fair amount of success for samples from the Prospect intrusion, on which a detailed magnetic survey has been conducted ; in the Sydney Basin area only general conclusions could be obtained.   Limitations of such correlations have been pointed out.

VIII. Acknowledgements.

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THE VOLCANIC STRATIGRAPHY OF THE MINYNON FALLS DISTRICT, N.S.W.

By Keith A. W. Crook,
and J. W. McGarity.

The Minynon Falls district is situated some 12 miles north-east of Lismore, and consists of rocks of Tertiary age. It is part of the Tertiary igneous province of N.E. N.S.W. to which, as a whole, reference has been made by Stonier (1895), while other authors have noted the occurrence of perlites and rhyolites, but have given no details. This paper serves merely as an introduction to the geology, since at the time of survey the authors were more concerned with the relation of the soil mantle to the various rock types.

STRATIGRAPHY.

The rocks of the Lismore area are mainly Tertiary volcanics, both flows and pyroclastics. These overlie the Jurassic Clarence Beds, and the Lower Paleozoic Nerangleigh Beds. The latter outcrop as an inlier at 615529 Nimbin.

The Tertiary volcanic sequence is not folded. Such complexities as do occur are apparently due to the uneven nature of the surface on which some of the formations were developed. The sequence in the Minynon Falls district may be summarised as follows : (See Fig. 2).

Minynon Falls Rhyolite	Gray to pink fluidal rhyolite, frequently columnar.	400′+
Boomerang Creek Obsidian	Red or black fluidal perlitic obsidian, sparsely porphyritic. ..	150′
Dorroughby Tuff	Crystalo-lithic rhyolite tuff, rich in volcanic quartz.	25′
Minynon Bole	Dark reddish brown compact bole.	3–6′
" Repentance Creek " Basalt	Sparsely porphyritic olivine basalt. Base not exposed.	?

" Repentance Creek " Basalt.

This, the lowest formation, occurs along river courses in the south and east of the district (Fig. 1), good outcrops being seen along Repentance Creek. It is part of the basalt of the Lismore plateau, which here passes beneath the later acid volcanics. The name " Repentance Creek " is used herein merely for convenience. It is not proposed to erect this as the formation name.

The basalt itself is rather variable. That near Repentance Creek is aphyric, whilst near Dorroughby phenocysts of feldspar and pyroxene are abundant. The former is fine, hypercrystalline and intergranular. The feldspar laths average $0·25$ by $0·05$ m.m. and show " frayed " ends. Some crystals are zoned, the thin outer rim being andesine, An_{35}, but the core, and the unzoned feldspar, is labradorite, An_{54}.

The pyroxene, titan-augite, may show ophitic relationships with the surrounding plagioclase. The olivine, granular and interstitial, has 2V (−) *ca.* 75°. It alters to a brown iddingsite-like material.

Iron ore is widespread, as small equant euhedra or as acicular crystals. Both ilmenite and magnetite may be represented. Minor amounts of glass occur as purple-brown isotropic patches. Small amounts of bowlingite, a serpentine-like mineral, but with $DR = 0.025$, are present in the interstices.

The type developed near Dorroughby has large labradorite and augite phenocysts, some of which are corroded, and show sieve-structure with respect to the groundmass. The groundmass is hyalopilitic, tending to intergranular. Glass is more abundant than in the former type, and olivine is subordinate. The composition of the constituents is similar, save that the augite is not noticeably titaniferous.

A third type, akin to the first, occurs on the Dorroughby-Minynon Falls road as an inlier in the rhyolite (see Fig. 1). This is fine, porphyritic in plagioclase, and is partly amygdaloidal. It is hypercrystalline and intergranular tending to sub-ophitic. The plagioclase is labradorite, that of the phenocrysts having 2V (+) *ca.* 80°, indicating An_{55}, whilst that of the groundmass is about An_{60}. The olivine has 2V (−) *ca.* 80°. It is fresh and occasionally contains chlorite inclusions. Iron ore is present as opaque acicular crystals.

No pyroxene remains, it being entirely replaced by a green alteration product (bowlingite?) which perfectly preserves the original ophitic relationship with the plagioclase. This material also occurs included in the phenocrysts and amygdules. Problematical patches of dark interstitial material, rich in iron ore occur. They are probably glass.

The "Repentance Creek" basalt comprises several flows, and between many of these, boles up to six feet thick have been developed. These may be seen at various points, particularly in road-cuttings, as at 578475 Nimbin. Here a bole may be seen sandwiched between two flows. The colour of the upper four inches is a dusky red (10R 3/2), thereafter grading to a weak red (10R 4/4) (Munsell System). Apart from these colour differences it is similar to the Minynon Bole which is developed on the topmost flow of the "Repentance Creek" basalt. Similar boles have also been described, interstratified in the Tertiary basalts, in the nearby Kyogle district (McGarity and Munns, 1955).

MINYNON BOLE.

This formation, although only six feet thick, is of importance geologically and pedologically. It comprises compressed and hardened clay material which undoubtedly represents a former soil developed on the underlying basalt, prior to burial by the acid volcanics. The type section is at Nimbin 573488 (Fig. 2) and it is named after the village of Minynon nearby.

The rock itself is dark reddish-brown (5YR 3/2, Munsell) and is dense and compact with a slightly conchoidal fracture. The hardness is 1 and the lustre is faintly greasy. On contact with water it disintegrates but does not expand noticeably.

DORROUGHBY TUFF.

This formation wedges out to the east and is not present near Minynon. Near Dorroughby, and again on the basalt inlier further north it is well developed. In hand specimen it could be mistaken for a porphyritic rhyolite, but the clastic nature is apparent in thin section.

Quartz is a prominent constituent, two types being present. The most common is very transparent, euhedral to subhedral and sharply angular. Free
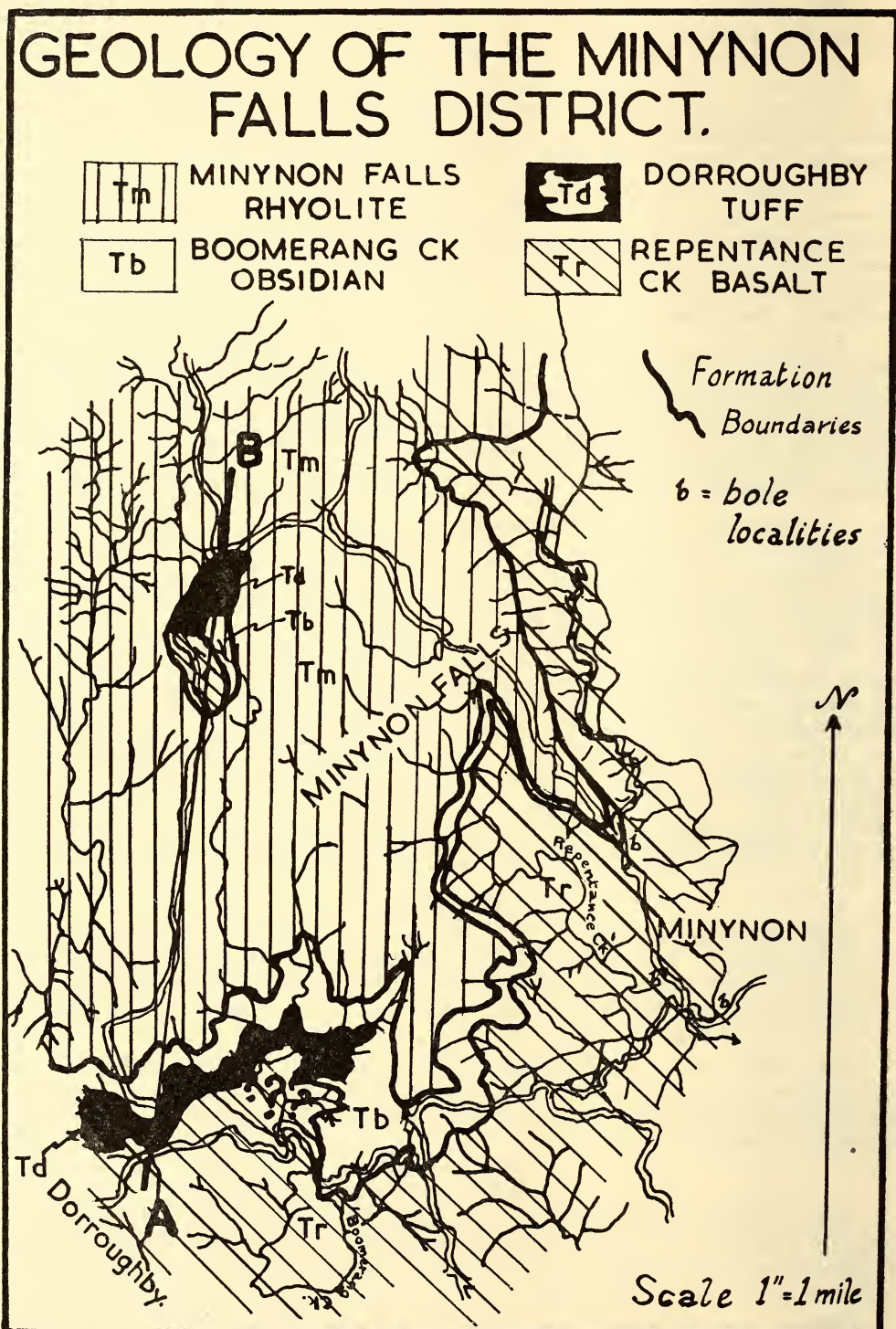
Text-fig. 1.—Geological map of the Minynon Falls District, N.E. of Lismore, N.S.W.

grains have an adamantine lustre, and show crystal faces. The margins of the grains may be concave and smaller fragments are shard-like. Partial replacement by chlorite occurs and embayments filled with matrix are present. Fractures, isotropic inclusions, rutile needles and muscovite and zircon inclusions occur. Small amounts of a second type, which is fairly well rounded, are present. These grains, some of which are composite, contain strings of fine bubbles, and are much less transparent. They are probably of sedimentary origin.

Large euhedral to subhedral crystals of sanidine are common. Most are quite fresh, clear and untwinned. The 2V (−) is small. Matrix filled embayments are present. Very minor amounts of oligoclase occur and also a little iddingsite, zircon and magnetite. Patches of an optically indeterminable zeolite, possibly stilbite (by analogy with the rhyolite), are present.

Rock fragments are a minor constituent, and are mainly igneous. Felsites and ?diabase are most frequent. A little metaquartzite is also present.
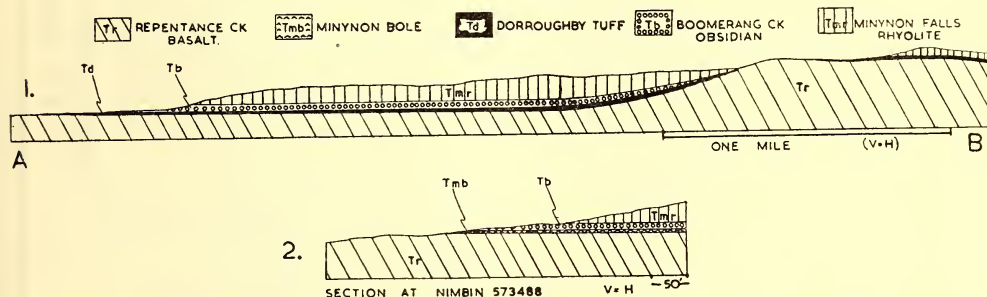
Text-fig. 2.—Cross-sections (1 : 1). No. 1, N.-S. along AB ; No. 2 in road cutting at junction in eastern centre of map.

These crystalline and lithic fragments are bound together by a matrix of irresolvable material, which is probably largely devitrified glass. The detrital fragments may be as large as 1·5 mm., but, for the sand fraction, the mode appears to be between 0·4 and 0·6 mm.

The percentage composition is :

Matrix 67%	Rock fragments 7%	Zeolite 1%
Quartz 19%	Feldspar 6%	

BOOMERANG CREEK OBSIDIAN.

This also thins to the east, being about 150′ thick at the type locality (525462 Nimbin) near Boomerang Creek, but having thinned to about 10′ near Minynon. Road-cuttings show good exposures with excellent flow banding, and associated contortions similar to sedimentary slumps. These 'slump' from the north. At two localities dips have been measured on the banding, that at 525462 Nimbin being to 3° E of N at 17°, and that at 573488 Nimbin being to 298° E of N at 8°. It appears, however, that these do not reflect the dip of the surfaces of the formation. Good outcrops occur in the creek to the east of the basalt inlier.

In thin section the obsidian is hyperhyaline, with incipient perlites and excellent fluidal banding. The rock is a colourless glass, with crystallites and rare phenocrysts of feldspar and pyroxene.

The pyroxene, hypersthene, has 2V (−) *ca.* 50°, and is pleochroic from pale yellow to pale green, the latter being the slow ray. The feldspar is
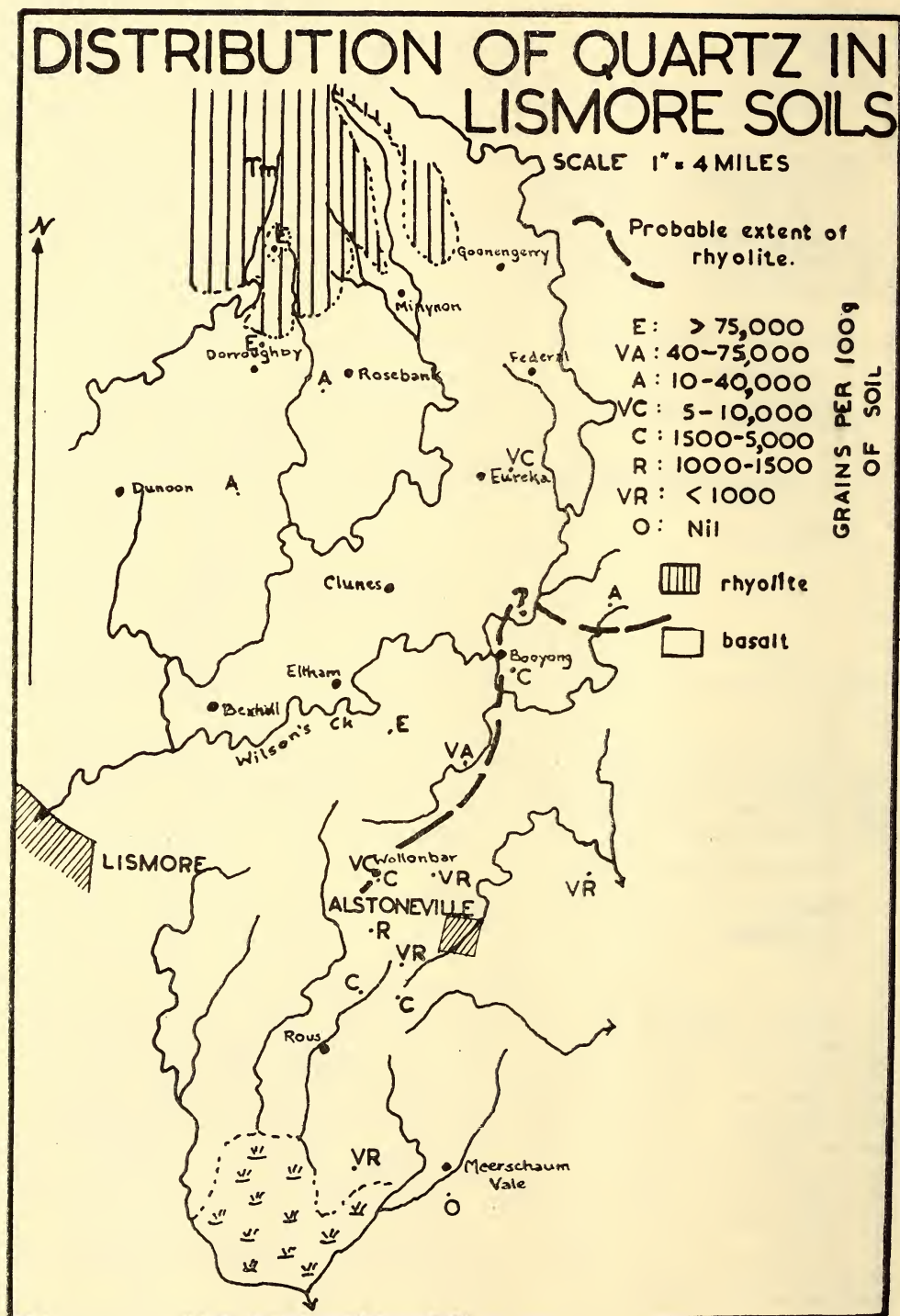
Text-fig. 3.—Distribution of volcanic quartz in basaltic soils near Lismore.

apparently albite, and has a large positive 2V.   Some elongated narrow prisms of magnetite are present.

The glass shows patchy devitrification, and is altered along fractures to palagonite.   It has an R.I. below that of balsam, and contains abundant rods or longulites (Rutley, 1891), probably of pyroxene, up to 0·1 mm. in length. These are generally oriented parallel, but may be violently disturbed along lines of turbulent flow.

At 673488 Nimbin the obsidian overlies directly the Minynon Bole.   Along the contact there has been some alteration of the obsidian, which has produced a soft pale pink " cheesy " material, having the colour 7·5R 8/4 (Munsell). This material is largely amorphous, and aggregate polarising, but minor amounts of sanidine are present.   It possibly represents a devitrified glass.

TABLE I.

Quantities of Quartz in Krasnozems in the Lismore District.

Locality.	Height in Feet above Sea Level.	Number of Grains per 100 Grammes of Soil.	Letter Symbol.
Li 576314	300	82,000	E
Li 614289	350	48,000	VA
Ni 545438	450	20,000	A
Ni 489405	450	20,000	A
By 698368	400	19,000	A
Ni 628415	500	6,000	VC
Li 566258	550	6,000	VC
Li 567259	550	3,000	C
Li 637342	400	2,000	C
Li 567198	600	2,000	C
Li 589188	650	1,300	R
Li 582235	550	1,000	R
Li 592204	600	1,000	R
Ni 645338	200	600	VR
Li 655254	400	400	VR
Li 585214	600	400	VR
Li 573155	400	300	VR
Li 594240	500	300	VR

MINYNON FALLS RHYOLITE.

This formation forms a good deal of the higher country to the north and north-east of Lismore, and is well developed at Minynon Falls (558506 Nimbin), where some 400′ is exposed on the face of the falls.   Here excellent columnar structure is visible.   In general the rhyolite is gray or pale pink, and is well banded.   The flow lines are much contorted.

In thin section the rhyolite is fine, aphyric, and generally holocrystalline. The lower portions of the formation however, contain some glass.   In the hypercrystalline varieties the glass has partly devitrified to give spherulites. In the holocrystalline varieties an " alteration " occurs along flow lines as localised patches which may link together leaving the unaltered material as clear spots.   This gives the rock a maculose appearance.   The nature of this " alteration ", if such it be, is difficult to determine.   It consists of fine acicular radiating material of high relief, which is irresolvable.

Quartz and feldspar are the major constituents.   The former is always interstitial and anhedral, whilst the latter, probably orthoclase, is euhedral. Biotite is widespread, but minor, and is euhedral or subhedral.   Rare grains

of zircon and magnetite euhedra occur. Quartz and a zeolite occur as deuteric minerals, in veins and patches. The zeolite has 2V (—) *ca.* 30°, $X'^\wedge c = 7°$, D.R. 0·005 and R.I. <balsam. These properties suggest stilbite.

The order of crystallisation is apparently : magnetite ; biotite ; acicular mineral ; feldspar ; quartz.

REGIONAL PICTURE.

The relationship of the acid volcanics to the underlying basalts is of interest. It is obvious, from the development of the bole between them, that an appreciable time break has occurred. Mohr and Van Baren (1954) quote an example of tropical weathering from Hawaii in which the rate of soil formation was considered to be 15 cms. per 1000 years and if this value is used to calculate the length of time taken for the bole to accumulate without allowing for compression, contemporaneous erosion and the like, a minimum figure of 6000 years is derived. Taking all these factors into account, the period between basic and acid activities appear to be at least of the order of 10,000 years. The boles developed within the " Repentance Creek " basalt indicate time breaks of a similar order occurred between the extrusion of the various flows.

It would seem that the acid volcanics were poured out on an uneven surface as indicated by the occurrence of the basalt inlier to the north of the main mass. It should be noted that there is a possibility that this may represent a later plug, intruded through the rhyolites, but the absence of any basalts capping the rhyolites in the district renders this improbable. The suggestion incorporated in Fig. 2 is tentatively put forward, and confirmation of it might be sought by means of a magnetometric survey of the district.

Consideration of the influence of the Minynon Bole on the soils of the district raised the question of the past extent of the acid volcanics. It was found that some clue could be gained from the distribution of volcanic quartz in the basaltic soils developed to the south. The quartz in these soils is largely an adamantine transparent type derived from the Dorroughby tuff.

The results of a series of analyses of basaltic soils (krasnozems) in the Lismore district is incorporated in Table I and Fig. 3. These results are semi-quantitative, and have been obtained by taking the sand fraction (2mm.—0·02 mm.) from 100g. of soil and estimating the number of quartz grains from a count of a representative sample. The distribution is not regular, but there is a definite fall-off in the frequency to the south-west of the line on Fig. 3.

It would appear that the Dorroughby tuff at least, and possibly other formations, extended across the valley of Wilson's Creek, i.e. at least twelve miles to the south of their present occurrence. The possibility of river transport of the quartz south of Wilson's Creek might be envisaged, but this is unlikely, for the occurrences are nearly on the surface of the Lismore Plateau. It seems unlikely that the acid volcanics ever reached Lismore, and there is no evidence for their presence in past times south of Meerschaum Vale, 25 miles south of Minynon.

ACKNOWLEDGEMENTS.

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LEUCOXENIC GRAINS IN DUNE SANDS AT NORTH STRADBROKE ISLAND, QUEENSLAND.

By H. G. GOLDING, A.R.C.S., B.Sc.

School of Mining Engineering and Applied Geology,
New South Wales University of Technology.

With Plate V and two Text-figures.

ABSTRACT.

Various leucoxenic grains occur in dune sands at North Stradbroke Island. Petrographic, chemical, density and X-ray data relating to the dominant variety is presented. Most grains consist largely of a minutely crystalline rutile or anatase base containing notable amounts of quartz inclusions. Internal and surface grain characters suggest that the inclusions are infillings of solution cavities formerly occupied by magnetite or hematite which existed as ex-solution intergrowths in the parent ilmenite. Unfilled and otherwise formed cavities are represented by a surface macroporosity. Such grains are probably formed in situ from ilmenite. Other grains lacking numerous inclusions and macropores may derive from more homogeneous ilmenites, from transported titania, or from other minerals. The possible utilization of the grains is considered.

INTRODUCTION.

In 1953 a bulk sample of dune sand from North Stradbroke Island was examined petrographically for heavy mineral content. The main constituents in order of abundance were rutile, ilmenite, zircon and a group of light coloured opaque grains, or " white opaques ", referred to leucoxene. In addition to the " white opaques " which were conspicuous numerically and by reason of their relatively large size and other grain characters, other varieties of leucoxenic grains occurred in lesser amounts.

In view of the economic utilization of certain leucoxenes (Gilson, 1949 ; Carpenter and others, 1953), and the varied data on recorded leucoxenes (Coil, 1933 ; Tyler and Marsden, 1938 ; Edwards, 1942 ; Creitz and McVay, 1948 ; Hutton, 1950), a study was made of the " white opaques " in the Stradbroke sample.

TABLE 1.

*Classification of Leucoxenic Grains in Dune Sands, North Stradbroke Island.*

Magnetic.	I	Ilmenite-leucoxene composites.	
Non-magnetic.	II	" White Opaques."	A. Pitted leucoxene-quartz aggregates. B. Mat-surfaced grains. C. Glossy grains.
	III	Amber-like grains.	
	IV	Rutile-leucoxene composites.	

PETROGRAPHY.

Most of the leucoxenic grains in the sample may be classified roughly on the basis of magnetic properties, colour, diaphaneity, surface characters and mineral association, into a number of groups (Table I). Detailed study was confined to group II grains, but brief notes are given also on the other groups.

Group I.   Ilmenite-Leucoxene Composites.

The leucoxenic substance in this group occurs usually as thin and discontinuous coatings through which the ilmenite core is visible.   Both fresh ilmenite and leucoxenized grains often show a few large pits and grooves, the latter occasionally of geniculate shape, suggesting the former presence of rutile.
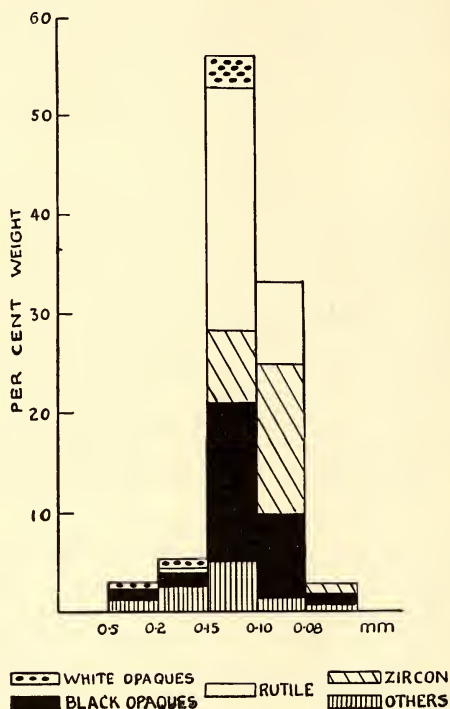
Text-Fig. 1.—Approximate Relative Size Distribution of Heavy Minerals in a Sample of Dune Sand from North Stradbroke Island.

White opaques refer to the dominant varieties of leucoxenic grains (group II).

Black opaques are mainly ilmenite, with minor leucoxenized ilmenite, magnetite, chromite and opaque rutile.

Rutile includes minor rutile-leucoxene intergrowths (group IV), and probably some of the amber-like grains (group III).

Others refer to non-opaque magnetic minerals grouped (tourmaline, garnet, epidote, staurolite, monazite, etc.).

Group II.   " White Opaques."

Most of the leucoxenic grains in the sample occur in this group which constitutes 4% to 5% by weight of the total heavy minerals.   Further, most of group II grains belong to sub-group IIA.   The approximate grain size and quantity relations of group II grains to the rutile, zircon and other minerals in the sample are indicated in Text Figure I.

Group IIA. *Pitted Leucoxene-Quartz Aggregates.*

Whole Grains.

These grains are conspicuous in non-magnetic fractions of the larger grades, 0·1 to 0·3mm. Colours are white, pale grey, cream or pale yellow, occasionally with a pink mottling. A few otherwise similar grains are brownish yellow or slate grey. Shapes are ellipsoidal to irregular, but a sub-discoidal shape is common in the 0·15mm. grades, some discs being broken (Plate 1, Figs. 1 to 3). Most grains are well rounded. The surface is characteristically punctate, being studded with numerous inclusions (or infilled pores), as well as empty pits or pores. Inclusions seem more numerous than voids, but often the distinction is uncertain. Most inclusions are of quartz, but some red or brown rutile (?) and orange anatase (?) blebs occur. Sizes of inclusions and pits vary from about 30μ to 1μ or less, but a diameter of about 10μ is common. As applied to cavities these dimensions are in the macropore range, the division into macro- and micropores being taken as 0·01μ (Ritter and Drake, 1945). Shapes of inclusions and pits are ovoid to irregular (Plate 1, Figs. 3 to 6), but a parallel lenticular arrangement is suggested in some grains. The amount of quartz visible as small inclusions is usually less than 5%, but peripheral films, outgrowths or larger attached grains of quartz are not uncommon. A few grains have a flaky appearance.

Texture of the surface between inclusions (or pits) at low magnifications resembles that of unglazed porcelain. At higher magnifications, also, it resembles that of unglazed porcelain viewed microscopically, i.e. the dull surface is relieved by scattered light reflections (Plate 1, Figs. 1, 3 and 6). When the reflections are lath shaped, or oriented in parallel, the presence of microlites is inferred, but in some grains clear, yellowish, or, less commonly, " rutile-brown " acicular crystals, isolated, or in parallel or intersecting bundles, are clearly visible at x 70. Apart from quartz blebs (protruding inclusions), or other quartz attachments, the grains are opaque.

Between crossed polars some grains exhibit a faint " luminescence ", an effect presumably resulting from polarisation and transmission of reflections through surface microlites. Where blebs or films of quartz occur these intensify the " luminescence ".

Crushed Grains.

Grains isolated and crushed in oil between slides are brittle, the fragments being opaque to translucent, and with incident illumination always light coloured, no ilmenite cores occurring. Anisotropism is heterogeneous, some fragments showing quartz colours, others 2nd or 3rd order tints, while cryptocrystalline to subcrystalline portions give a cloudy aggregate polarisation effect. As the slides are moved over each other the subcrystalline portion partly resolves further into anisotropic " light points ".

The dry powder is cream coloured as contrasted with the brown of pulverized rutile. Both mineral powders are difficultly or partially soluble, to about the same degree, when heated in concentrated sulphuric acid, the solutions reacting for titanium with chromotropic acid or phenol.

Sectioned Grains.

A few grains were sectioned to a thickness of minus 30μ, after mounting in phenolic resin which permits grinding to thinner sections than is possible with balsam. Numerous isolated and interconnected quartz inclusions, some of very irregular shape (Plate 1, Figs. 10 and 11) occur in an opaque base of vaguely granular character. In places, especially toward boundaries of quartz and " groundmass ", the latter is pellucid revealing the presence of transparent

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acicular microlites or granular meshworks, of high relief and birefringence. The meshworks may be anatase, or bundles of rutile microlites. Some micro-lites grow out from the base and penetrate areas of quartz (Text-Fig. 2). Both microlites and meshworks were noted in a single grain, and associated with a single quartz inclusion, but in most grains one or the other structure predominated. Minute inclusions, single microlites, meshwork granules (?), and portions of " groundmass ", occur within some quartz areas. Rarely quartz areas consist of more than one optical unit, and occasionally a straight junction of quartz and base suggests a crystal face of quartz. In a few cases quartz or chalcedony envelope whole grains. Total quartz present in sections varies from about 5% to 40%. Voids are rare and may have been induced by sectioning. In one grain, however, a central space within a quartz area seemed natural, the quartz around the space being peppered with minute inclusions.

A comparison with sectioned leucoxenes from other sources was provided by examination of slides of Hawkesbury Sandstone. These rocks contain leucoxenic material of types IIA and IIB, many of the grains being deformed and fragmented. Group IIA grains exhibit cavities, embayments, and inclusions of quartz and clay minerals.
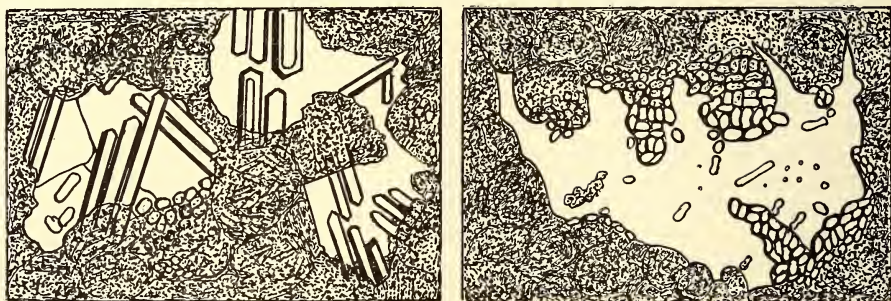
Text-Fig. 2.—Schematic Representation of Quartz Inclusions in Leucoxenic Grains (Group IIA).

Group IIB.   Mat-Surfaced Grains.

These grains differ from those of group IIA merely by reason of finer texture, neither numerous inclusions and macropores per grain, nor microlites, being visible at magnifications used. The surface suggests that of unglazed porcelain when the latter is viewed macroscopically. Some grains show a few large inclusions and macropores per grain, however, and others have cracks cemented with quartz. Sizes are usually minus 0·2mm, and normal discoidal shapes were not seen, but a few grains are elongate, or discoidal with an elongate central bulge, suggesting a rutile core ; these perhaps should be classed with group IV. The grains are brittle and on crushing exhibit heterogeneous anisotropism, i.e. cloudy material and " light points ", particle sizes being too small for further resolution.

Group IIc.   Glossy Grains.

Highly rounded grains, globular to irregular in shape, having smooth lustrous surfaces, are included here. Reflections are highlights (Pettijohn, 1949) so that the likeness is to glazed rather than unglazed porcelain, or to pellets of some synthetic plastics. Shallow indentations, invaginations, and cracks (Plate 1, Fig. 7), some of them quartz-filled occur. Sizes are usually minus 0·2mm. Colours are commonly cream, but some coffee brown and dark grey tints occur. In some grains the bulk of the crushed fragments show strong

birefringence, in others almost no resolution into " light points " could be effected.   The grey grains seemed more crystallized than the brown or cream. Brittleness also is variable.   Pulverized cream grains gave a titanium reaction with chromotropic acid.

Group III.   Amber-Like Grains.

Grains of amber tints and resinous lustres in incident light, opaque centrally but variably translucent peripherally, of ovoid to blocky shapes, occur in the minus $0 \cdot 2$mm sizes, and are present in the order of one percent by weight of the heavy minerals.   Some are distinguished with difficulty from glossy grains (IIc), and suggest that glossy grains were " clearing ", and perhaps beginning to develop a single crystal character, as reported for some anatase (Broughton and others, 1950).   In incident light the distinction from some rutile is also uncertain, but the relative opacity and cloudy anisotropism of whole grains, and their failure to extinguish, serve to differentiate them, in transmitted light, from normal varieties of rutile.   Crushed fragments are strongly birefringent, a little cloudy material also occurring.   Some of these grains are associated with leucoxene of type IIB, suggesting amber partly coated with white powder. A few grains are flaky.   Exterior quartz attachments occur.

Group IV.   Rutile-Leucoxene Composites.

These grains are moderately numerous in the minus $0 \cdot 15$mm. grades, but usually only a small amount of leucoxene is attached to the dominant rutile grain, the rutile being of normal single crystal character, and occurring either as one unit or as several lamellæ per grain.   The leucoxene is often very fine grained (IIB or possibly IIc).   Some of these grains viewed with both incident and transmitted light simultaneously, show sharp edged films or fingered intergrowths of white leucoxene and red rutile (Plate 1, Figs. 8 and 9). Tyler and Marsden (1938) suggest a leucoxene→rutile transformation for this association.   The bulging types noted under Group IIB, and the illustration (Plate 1, Fig. 8) however, seems to suggest the reverse, or (Plate 1, Fig. 9) may point to a composite parent material, several of which are described by Edwards (1954, 73, 74).

CHEMICAL, DENSITY AND X-RAY DATA.

About $0 \cdot 5$gm. of pure Group II material, mostly IIA, was isolated as follows. The sand was panned, sieved, fractioned in bromoform and electromagnetically, to give a non-magnetic concentrate of rutile, zircon and leucoxenic grains (all groups except Group I).   Dry panning gave concentrates richer in leucoxenic grains.   Cleaner fractions were obtained in part using cooled methylene iodide, and in part with Clerici solution, but 20% floats were contaminants.   The final product was obtained by removal of all unwanted material by handpicking under the binocular.

Chemical Analysis.

The analysis shown below (Column 1, Table II) was obtained from about $0 \cdot 1$ gm. of material.

The analysis of the Stradbroke grains compares closely with that of Coil (1933).   Coil refers to quartz impurity as being visible under the microscope in the sample before analysis, but it is not clear whether the quartz was present as separate grains contaminating the concentrate, or occurred within, or attached to, the leucoxenes, as is the case with the Stradbroke material.   Tyler and Marsden (1938) did not find quartz lines in a diffraction pattern of leucoxene from the same source (Garber Sandstone).

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Grain Specific Gravity and Specific Gravity of the Leucoxenic Substance.

About 100 grains were immersed in Clerici solution of various concentrations, the specific gravity of the solution being obtained from its refractive index, using Vassar's data (Twenhofel and Tyler, 1941). The following results were obtained :

R.I.	S.G.	
1·600	3·44	All grains float.
1·586	3·32	Most grains sink.
1·574	3·22	All grains sink.

Hence the specific gravity of most of the grains lies between 3·30 and 3·42. These results are lower than those hitherto recorded for leucoxenes, and presumably reflect the high quartz content of the grains, and, to a lesser extent, the presence of voids.

TABLE 2.

Chemical Analyses of Leucoxenic Materials.

	1 Stradbroke, Group II.	2 Garber Sandstone.	3 Boolarra Bauxite.	4 Trail Ridge Dunes.
TiO_2	67·6	72·12	86·6	86·9
SiO_2	27·6	24·49	1·2	—
Al_2O_3	n.d.	—	0·5	—
Fe_2O_3	$\{$ 1·9	0·50	$\{$ —	7·6
FeO	$\{$ n.d.	1·35	$\{$ 3·6	—
CaO	n.d.	—	n.d.	—
MgO	n.d.	—	n.d.	—
H_2O	1·1 =total water	1·66	8·0	—
	98·2	100·12	99·9	94·5

1. Group II leucoxenic grains, North Stradbroke Island dunes. (Analyst, G. See.)
2. Leucoxene concentrates, Permian Garber Sandstone, Oklahoma. (Coil, 1933.)
3. Leucoxene, Cainozoic bauxite, Boolarra, Victoria. (Edwards, 1942.)
4. Concentrate containing 80·9% of a non-magnetic leucoxene, plus rutile, corundum, kyanite and zircon, dune sands, Trail Ridge, Florida. (Creitz and McVay, 1948.)

If the values for the specific gravities of Group II grains, silica and Fe_2O_3 be assumed as 3·36, 2·66 and 5·2 respectively, and analysis values be rounded to 68% Ti_2O_2, 28% Si_2O_2, 2·5% Fe_2O_3 and 1·5% H_2O, the approximate specific gravity of the quartz-free leucoxenic substance in the Group II grains would be 3·63+, i.e. the value would probably be low due to voids. These figures compare with those of other investigators as follows (Table III).

X-Ray Analysis.

The powdered material was analysed with a Geiger-counter X-ray diffracto-meter. The interplanar spacings obtained were compared with cards of the A.S.T.M. Index of X-Ray Diffraction Data, 5th set, (1953). Three constituents were identified : rutile, quartz and anatase. Diffraction data are listed in Table IV.

TABLE 3

Specific Gravity of Leucoxenic Materials and Leucoxenic Substance.

		1 Stradbroke.	2 Coil (1933).	3 Edwards (1942).	4 Creitz and McVay (1948)
Grain S.G. of impure concentrate or aggregate.	Average ..	3·36	3·828	3·56 (almost pure)	—
	Limits ..	3·30–3·42	3·65–4·005	—	3·9–4·1
Computed S.G. of leucoxenic substance		3·63+	4·17	3·56	—

TABLE 4.

X-Ray Powder Data for Group II Leucoxenic Grains, North Stradbroke Island Dune Sands.

2θ Degrees.	d Å.	Relative Intensity.*	Reflection Caused by.
21·0	4·23	15	Q.
25·4	3·51	39	A.
26·8	3·33	95	Q.
27·5	3·24	100	R.
36·2	2·482	38	R.
36·6	2·456	8	Q.
37·8	2·38	6	A.
39·4	2·286	8	Q.
39·6	2·298	8	R.
40·4	2·232	5	Q.
41·4	2·181	15	R.
42·5	2·125	5	Q.
44·2	2·049	9	R.
46·0	1·972	4	Q.
48·2	1·889	9	A.
50·3	1·815	11	Q.
54·4	1·685	47	R.
56·7	1·622	16	R.
60·0	1·541	7	Q.
62·8	1·479	10	R.
64·2	1·450	8	R.
68·3	1·372	9	Q., A.
69·1	1·36	20	R.
69·9	1·345	10	R.
77·7	1·228	2	Q.
80·0	1·199	3	R.
81·2	1·185	2	Q.
81·5	1·180	3	Q.
82·6	1·167	6	R., A.
83·4	1·159	1	Q., A.
84·4	1·149	3	R.
89·7	1·092	4	R., A.
90·8	1·082	4	R., A., Q.
92·8	1·064	1	Q.
95·3	1·043	7	R., Q.
96·1	1·036	5	R.
97·4	1·025	3	R.
98·8	1·015	1	Q.
102·3	0·989	3	Q.
104·2	0·976	2	Q.

R.=rutile, Q.=quartz, A.=anatase.

* Peak heights on diffractometer chart. Ni filtered Cu K_α radiation.

SIGNIFICANCE OF CERTAIN GRAIN CHARACTERS.

1. *Quartz Inclusions and Macropores.*

Silica now represented by quartz inclusions within Group IIA grains may be :

(a) Silica present in the parent material. Derivation of the grains from materials such as rutilated quartz, rutile-granular quartz veins (Beasley, 1950), sphene (Culey, 1938), titanaugite (Hanlon, 1944), biotite, or mixed silica and titania gels (Brammal and Harwood, 1923), might thus be envisaged.

(b) Clastic quartz incorporated during a plastic stage, or during authigenic formation in sediments as with some replacement cherts (Williams and others, 1954).

(c) Replacements of portions of the grain by silica of later date.

(d) Infilling of former cavities by silica of later date.

The infilling of former cavities seems likely as the dominant factor involved for the following reasons :

(a) The enlargement and clearing of microlites and crystal meshworks toward boundaries of leucoxenic base with quartz, and the outgrowth of microlites from the base into areas of quartz, suggest a former free space.

(b) One instance of a central void occurring within a quartz area suggests incomplete filling.

(c) The presence in other leucoxenes (Brown, 1928) of numerous empty penetrating pores.

The internal cavity shapes however, would have been modified by crystal growth, as noted above, and also perhaps by some wall replacement and " microstoping " accompanying infilling. The minute inclusions within quartz areas may thus be replacement residuals. Diagenetic replacement by matrix minerals (later removed) may also have contributed to cavity modifications in the outer portions of grains.

The pitted surface of leucoxenes has been remarked by Milner (1952), Beasley (1950) and Brown (1928). The last named author described irregular and oriented openings or perforations in leucoxenes from the Permian sandstone of Oklahoma. Brown regarded the openings as solution cavities formerly occupied by magnetite which had occurred as ex-solution intergrowths in the parent ilmenite. Solution may have occurred during laboratory treatment with acid, but if so its occurrence in nature, under appropriate conditions, as in the reducing zones discussed by Miller and Folk (1955), may be expected. Hematite and rutile might also be involved in such ilmenite intergrowths. Solution of magnetite and hematite would thus result in relict intergrowth void textures which would include oriented types (Edwards, 1954, 70–77). Conceivably the more stable rutile crystals present in some intergrowths would be left within cavities so formed, later to be incorporated as part of the minute inclusions noted in quartz areas. Presumably solution of iron minerals might occur before, during or after leucoxenization. Oriented voids were not recognised with certainty in the Stradbroke grains, but were suspected in some. Modifications of cavity shapes may have obscured such textures.

Assuming an ilmenitic parent, the low iron value obtained in the analysis points to the removal of most of the normal iron, together with any excess present as compounds in solid solution. Precipitation of disseminated iron compounds, accompanying leucoxenization, and their subsequent solution to

form cavities, might thus be envisaged without recourse to former intergrowths. Diffusion to centres of precipitation, however, would be necessary if sizeable macropores were to eventuate. If removal of the normal iron occurs through innumerable micropores however, some fine grained types (IIB) might be ascribed to ilmenite parents lacking sizeable intergrowths whereas Group IIA grains would be referable to well developed ilmenite intergrowths. Examination of ilmenites from suspected source rocks conceivably might thus bear on ultimate provenance of particular leucoxenes.

If solution of iron minerals is responsible for most of the cavity formation, the origin of Group IIA grains at the site of former ilmenite seems likely, since transport of leucoxenic material in solution or suspension would tend to destroy the disseminated void structure.

Some surface cavities in Group IIA grains resemble various organic and vesicular structures, but the possibility that such structures are in fact represented is remote. Structures which might be designated " sedimentary vesicles " are described by Twenhofel (*ibid* 622–3), these include crater-like openings, pits and tubes, formed experimentally in muds by egress of fluids. The microporosity characteristic of various colloidal materials might be supposed in certain conditions, as by rapid expulsion of contained fluids, to promote a macroporosity.

Processes considered more likely to have contributed to the surface structures in Group IIA grains include differential plucking and gouging acting respectively on locally hard and soft, or variably particulate, portions of the grain surface. Such variations are presented by the variably crystallized granular base, sporadically distributed microlites and groups of microlites, and by inclusions mostly of quartz. Removal of quartz in this way would result in " second order " or re-formed cavities. The collapse of cell walls, and corrosion by matrix minerals, would effect further modifications at appropriate stages during grain history.

It is concluded tentatively that solution of iron minerals, probably former intergrowths within ilmenite, is responsible for the formation of most macropores in Group IIA grains, but that other processes have modified, and perhaps made independent contributions, both to internal and external cavity formation.

Cracks, usually cemented with quartz, which occur in fine grained and glossy grains, presumably are referable to dehydration, or to stresses accompanying compaction. Shallow indentations on glossy grains suggest pressure on plastic material at grain contacts, rather than pressure and solution at grain contacts ; or slumping in plastic material.

2. *Gloss.*

Processes thought to induce gloss include solution, deposition of thin films, gentle attrition, sandblasting and passage through organisms (Pettijohn, 1949). A few glossy grains (IIC) are probably fine grained (IIB) grains covered with a thin film or glaze of quartz. In minerals of colloidal origin, however, an originally free surface becomes typically smooth and lustrous, corresponding to the " skin " of a gel (Edwards, 1954, 20), and it seems likely that most of the glossy Stradbroke grains are so formed. Possibly some fine grained types (IIB) develop by further dehydration and crystallization of material which otherwise would form glossy types, in a manner analagous to the formation respectively of crystalline goethite and glassy limonite (Edwards, 1954). Conceivably abrasion of the " skin " might " transform " a glossy grain into a fine grained one.

3. *Shape.*

According to Twenhofel (1950) discoidal grains develop by abrasion of particles having two long and one short dimension. Ilmenite, anatase and

brookite might satisfy this condition. If an increase in volume accompanies leucoxenization a discoidal shape might also be promoted by authigenic formation in stratified rocks, in a manner partly analagous to that in which some discoidal concretions form (Tarr, 1933), and partly analagous to the swelling of some clays or gels on hydration. If swelling is involved it would modify the shapes of pre-existing or penecontemporaneous cavities, and perhaps influence the removal of iron minerals. The precipitation of a gel on a depositional floor might form spheroidal particles, subsequently flattened by accumulating overburden, as suggested by Twenhofel (*ibid*) for some chert. Authigenic formation and abrasion, rather than flattening, are here assumed to have influenced the shape of the larger Group IIA grains. Glossy grains frequently present a spheroidal or mammillary form often indicative of gel origin in unconfined conditions, as suggested above for some chert, and also by Edwards (1954) for several minerals exhibiting colloform textures.

4. *Colour.*

Creitz and McVay (1948) from spectrochemical analysis of ferriferous magnetic leucoxenes noted an increasing Fe:Ti ratio from yellow to brown, and brown to black grains. The generally light colours of the group II grains conform similarly to the low iron values obtained in the analysis. In the case of precipitated iron oxides however, colour alters with ageing, brown changing to red with the growth and agglomeration of particles, and the loss of adsorbed water (Weiser, 1935 ; Milligan, 1952), and it seems likely that these factors have also influenced the colours in leucoxenes. Williamson (1940) suggested additional factors which possibly influence colour and colour phenomena in artificial TiO_2. These included the presence of thin films of rutile on anatase, and adsorption of ferric oxide on rutile surfaces, factors in turn probably dependent on the presence of impurities, the chemical and pressure environments of formation and the thermal history of the material.

Mode of Origin and Source of Group II Grains.

It is considered likely from the foregoing observations that Group II grains passed through an early hydrogel stage, either as whole grains (glossy types) or in a piecemeal manner (pitted types), but that a variable, and usually advanced stage of crystallization and dehydration has been attained in most cases. Titania, the main chemical constituent occurs in microcrystalline and perhaps more finely crystalline states, both as rutile and anatase, and presumably single grains contain a predominance of either one or other of these minerals. Other early formed constituents include small quantities of iron compounds and adsorbed or microporous water, these occurring perhaps in the subcrystalline portions of the grain which may also contain some titania and silica.

Group IIA grains are referred tentatively to an ultimate formation in situ from ilmenite, and probably in most cases from ilmenite-magnetite or ilmenite-hematite intergrowths. Solution of iron compounds left cavities subsequently modified by various agencies and largely infilled with silica, which in some cases enveloped whole grains. Group IIA grains are thus leucoxene-quartz aggregates. They have a variable, mainly surface macroporosity, as well as probable microporosities perhaps of more than one origin. Silica reinforcement has probably influenced the persistence of the grains which may thus have withstood repeated cycles of sedimentation and beach reworking while unsilicified grains became fragmented. That some comminution occurs, even of silicified grains however, is indicated by the diagenetic fragmentation and deformation observed in grains in the Hawkesbury Sandstone. It is also suggested by the broken discoidal grains in the Stradbroke material.

Glossy grains (IIc) are assumed to consist of relatively pure (quartz-free) titania. The poorly crystallized grains may be more hydrous, and the darker coloured grains more ferriferous, than others. Such grains are regarded tentatively as deriving from transported titania hydrosol. Gelation or colloidal precipitation, and subsequent hardening, occurred in unconfined conditions. The titania may have originated from non-ferriferous titanium minerals, but may also have derived from ilmenite by the removal of that mineral in solution or colloidal suspension. Subsequent differential precipitation of titania-rich and iron-rich fractions, in suitable environments, might thus be envisaged.

Fine grained types (IIB) are probably referable to various origins. Some may arise by leucoxenization in situ of relatively homogeneous ilmenites, others from alteration of rutile or rutile-ilmenite intergrowths, and some perhaps from transported titania.

The separate use of the terms leucoxene and doelterite for anhydrous microcrystalline and hydrated isotropic titanium dioxide respectively (Hutton, 1950) does not seem valid for the Stradbroke grains which show transitional features.

The surface characters of the Stradbroke grains do not correspond closely with those noted by Tyler and Marsden (1938), since rounding and polish are related, by those authors, only to detrital grains, and secondary grains are described as usually porous, but also as soft and earthy. Silicification of the Stradbroke grains, however, is partly responsible for their brittleness.

Probable immediate source rocks for Group IIA, and some IIB, grains are Mesozoic sandstones (Beasley, 1950). Whereas most minerals in such rocks are detrital however, the status of leucoxene in this respect is doubtful, and according to Smithson (1939) not determinable for leucoxenes in Jurassic sandstones of Yorkshire. Authigenic formation within Mesozoic sandstones, followed by a Hawkesbury " type " of silicification (Osborne, 1948) may be involved.

Rocks such as the Hawkesbury Sandstone might contribute only a small part of their contained leucoxene to the beach sands, however, the finely comminuted material perhaps being deposited among silts and muds.

The high titania contents of some laterites and bauxites (Sherman, 1952, Hanlon, 1944) and the presence in others of various leucoxenes (Edwards, 1942, Frederickson, 1952) suggests formations of this type as other possible sources. From such rocks the smaller Group IIA grains, fine grained and glossy types, rather than discoidal and silicified grains, might be expected. Macroporous types, if unsilicified, might fail to withstand transport.

ECONOMIC CONSIDERATIONS.

Since the field sample examined was a bulk sample, the occurrence of higher concentrations of leucoxenic grains, and other heavy minerals, at particular levels, or locations, in the dunes, is possible. It seems unlikely that concentrations of light-coloured grains (e.g. leucoxenes, zircon or garnets) would occur unassociated with " black opaques " and rutile, in South Queensland sands, but if they did, they might be overlooked by those prospecting for " black sands ".

If the single analysis on the small sample be assumed as representative, the group II Stradbroke grains contain a rather lower TiO_2 content than the economic leucoxenes of Trail Ridge (Gilson, 1949, Carpenter and others, 1953). If all the " white opaques " were recovered with the rutile the resulting concentrate would contain some 12% by weight of " white opaques " or about 96% TiO_2 and 3% SiO_2. An industrial rutile concentrate from beach workings in the area contained about 3% " white opaques " and 1% of amber-like grains.

Large discoidal IIA grains were less common than in the dune sand sample. The natural beach sand was not available for examination, but it seems likely that a significant proportion of leucoxenic grains is recovered with the industrial rutile.

Assuming chemical properties comparable with those of rutile for most leucoxenic grains, then, apart from their silica content, they would serve merely to augment the TiO_2 content of rutile concentrates. If, however, there were reasons for removing or separately recovering the leucoxenic grains, their surface features suggest that flotation processes might be effective.

The porosity of the material, considered together with its other chemical and physical characters, conceivably might recommend it for uses such as adsorbents or catalyst carriers. Ritter and Drake (1945) note that for such materials microporosity contributes the bulk of the reactive surface area, but macropores serve an important function as distributing arteries, the size distribution of the macropores, as well as the total macroporosity being significant. While the internal macroporosity of the Stradbroke grains, has been largely destroyed by silica infillings, the residual porosity, possibly, may be worth investigating. It seems likely that leucoxenes exist (Brown, 1928) which are more porous than is the case with the grains examined, or in which porosity could be artificially induced. Such grains, however, may occur in sedimentary rocks rather than on beaches. The age and diagenetic history of particular sediments, might bear, among other factors, on the occurrence within them of macroporous leucoxenes.

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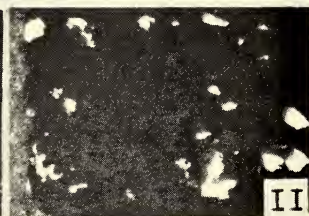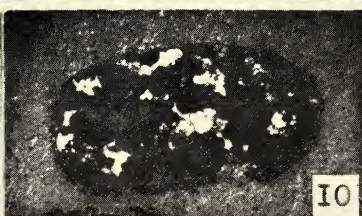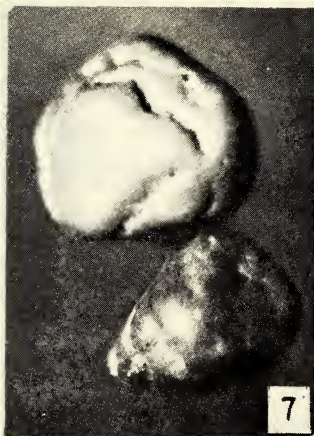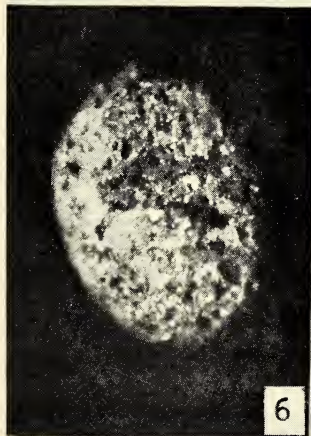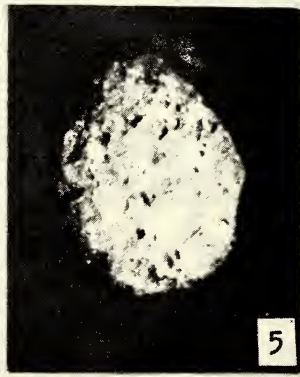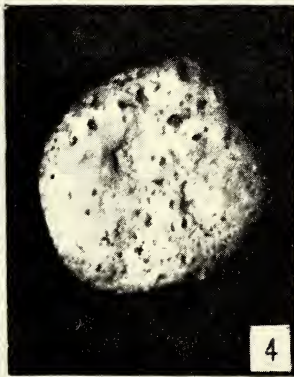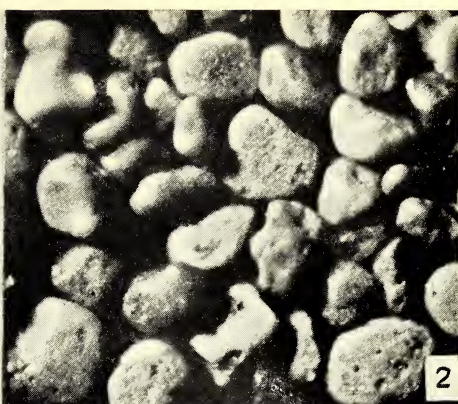
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Fig. 1.—Nonmagnetics, unsized. Two broken sub-discoidal gp. II A grains centre, glossy grain at lower left. Rutile dark, zircon uncoloured. X 45.
Fig. 2.—" White opaques ", general appearance of concentrate. A large glossy grain at upper left. X 45.
Fig. 3.—Gp. II A sub-discoidal grain, minute lath-like reflections indicate microlites. X 100.
Fig. 4.—Gp. II A grain showing shape, rounding, inclusions, macropores and gouge (?) pits. X 100.
Fig. 5.—Gp. II A grain showing shape, inclusions and macropores. X 100.
Fig. 6.—Gp. II A grain showing shape, inclusions and macropores. X 100.
Fig. 7.—Two glossy II C grains, with cracks.
Fig. 8.—Gp. IV grain. Fine grained leucoxene wrapping round rutile. X 160.
Fig. 9.—Gp. IV grain. Leucoxene-rutile intergrowth. X 100.
Fig. 10.—Sectioned Gp. II A grain showing shape and distribution of quartz inclusions. ×100.
Fig. 11.—Portion of sectioned Gp. II A grain. ×100.

ON WEBER TRANSFORMS.

By James L. Griffith, B.A., M.Sc.
School of Mathematics, New South Wales University of Technology.

SUMMARY.

There are two forms of the Weber Transform. The first, denoted by the operator T_1, is given by

A_1: If $\nu \geq 0$ and $x^{\frac{1}{2}}f(x)$ belongs to $L^1(a, \infty)$, $a > 0$,

$$F(s) \equiv T_1[f(x)]$$
$$= \int_a^\infty x C_\nu(xs, as) f(x) dx \quad \ldots \ldots \ldots \quad (\text{S.1})$$

(the integral converges absolutely).

We have used the notation

$$C_\nu(\alpha, \beta) = J_\nu(\alpha) Y_\nu(\beta) - J_\nu(\beta) Y_\nu(\alpha), \quad \ldots \ldots \ldots \quad (\text{S.2})$$

where $J_\nu(\alpha)$ and $Y_\nu(\alpha)$ are the Bessel functions of the first and second kind of order ν.

The second form denoted by the operator W_1 is defined as follows:

B_1: If $s^{\frac{1}{2}}G(s)/Q_\nu(as)$ belongs to $L^1(0, \infty)$,

$$g(x) \equiv W_1[G(s)]$$
$$= \int_0^\infty \frac{s C_\nu(xs, as)}{[Q_\nu(as)]^2} G(s) ds \quad \ldots \ldots \ldots \quad (\text{S.3})$$

(the integral converges absolutely).

Here we have used the notation

$$[Q_\nu(\alpha)]^2 = [J_\nu(\alpha)]^2 + [Y_\nu(\alpha)]^2 \quad \ldots \ldots \ldots \quad (\text{S.4})$$

The inversion theorem for the T_1-transform was given in [T.W.I.] (see references at end of paper) and states that, whenever $f(x)$ is of bounded variation near a point x,

$$\tfrac{1}{2}\{f(x+0) + f(x-0)\} = \lim_{\lambda \to \infty} \int_0^\lambda \frac{s C_\nu(xs, as)}{[Q_\nu(as)]^2} F(s) ds \quad \ldots \ldots \quad (\text{S.5})$$
$$\equiv T^{-1}[F(s)].$$

Similarly, the inversion of the W_1-transform is given by

$$\tfrac{1}{2}\{G(s+0) + G(s-0)\} = \lim_{\lambda \to \infty} \int_0^\lambda x C_\nu(xs, as) g(x) dx$$
$$\equiv W^{-1}[g(x)] \quad \ldots \ldots \ldots \quad (\text{S.6})$$

at any point at which $G(s)$ is of bounded variation.

The author of this paper has been unable to find formula (S.6) in the literature available to him and a proof has been given in the Appendix.

It will be seen that the transforms T_1 and W_1^{-1} will be equivalent only if $x^{\frac{1}{2}}f(x)$ belongs to $L^1(a, \infty)$ and $s^{\frac{1}{2}}\{T_1[f(x)]\}/Q_\nu(as)$ belongs to $L^1(0, \infty)$, since the integrals in equations (S.6) and (S.7) do not necessarily converge absolutely.

In §3 of the paper, we assume that $x^{\frac{1}{2}}f(x)$ belongs to $L^2(a, \infty)$ and $s^{\frac{1}{2}}G(s)/Q_\nu(as)$ belongs to $L^2(0, \infty)$ and define a T and a W-transform (denoted by T_2 and W_2 respectively) so that, if

(i) $x^{\frac{1}{2}}f(x)$ belongs to both $L^1(a, \infty)$ and $L^2(a, \infty)$ then $T_1[f(x)]=T_2[f(x)]$,

(ii) $s^{\frac{1}{2}}G(s)/Q_\nu(as)$ belongs to both $L^1(0, \infty)$, and $L^2(0, \infty)$, then

$W_1[G(s)]=W_2[G(s)]$.

These definitions will allow an identification between T_2 and W_2^{-1} which can be expressed as:

To every $f(x)$ for which $x^{\frac{1}{2}}f(x)$ belongs to $L^2(a, \infty)$, there corresponds a unique function $F(s)$, for which $s^{\frac{1}{2}}F(s)/Q_\nu(as)$ belongs to $L^2(0, \infty)$ (and conversely). The functions $f(x)$ and $F(s)$ are connected by

(a) $F(s)=T_2[f(x)]=W_2^{-1}[f(x)]$

(b) $\displaystyle =\text{l.i.m.}_{p\to\infty}\int_a^p xC_\nu(xs, as)f(x)dx,$

(c) $f(x)=T_2^{-1}[F(s)]=W_2[F(s)]$

(d) $\displaystyle =\text{l.i.m.}_{p\to\infty}\int_0^p \frac{sC_\nu(xs, as)}{[Q_\nu(as)]^2}F(s)ds,$

provided that we identify functions which are equal almost everywhere.

This result is contained as part of Theorem 3.1 in the text, which is clearly a theorem of the Plancherel type.

Incidently, in the proof of the theorem 3.1, the Parseval formula

$$\int_a^\infty xf(x)g(x)dx=\int_0^\infty \frac{sF(s)G(s)}{[Q_\nu(as)]^2}ds$$

is proved.

In §4, the T_2-transform of a function which is zero outside a finite interval is examined. The conclusion which connects these functions with a certain class of integral functions is expressed in the theorem:

In order that $x^{\frac{1}{2}}g(x)$ belongs to $L^2(a, \infty)$ and

$$g(x)=0, \text{ for } x>b>a,$$

it is necessary and sufficient that

(i) $s^{\frac{1}{2}}G(s)/Q_\nu(as)$ belongs to $L^2(0, \infty)$,

(ii) $G(z)$ is analytic in $z=s+i\beta$ for all β,

(iii) $G(ze^{i\pi})=G(z)$ and

(iv) $|zG(z)|=O(e^{(b-a)|\beta|})$ as $|z|\to\infty$.

U

1

When we are considering functions in L^1-space, there are essentially two different types of Weber Transforms. In order to state these in the form required for this paper, we will use the following notations mentioned in the summary :

If $J_\nu(\alpha)$ and $Y_\nu(\alpha)$ are the Bessel functions of the first and second kind, defined on p. 8 and p. 64 of [W.B.F.] respectively, we write

$$C_\nu(\alpha, \beta) = J_\nu(\alpha)Y_\nu(\beta) - J_\nu(\beta)Y_\nu(\alpha) \quad \ldots\ldots\ldots\ldots \text{(1.1)}$$

and

$$[Q_\nu(\alpha)]^2 = [J_\nu(\alpha)]^2 + [Y_\nu(\alpha)]^2. \quad \ldots\ldots\ldots\ldots\ldots \text{(1.2)}$$

The form of the Weber transform, which was treated in detail in [T.W.I.], is defined with its inverse in the theorem

A_1 : If $\nu \geqq 0$ and $x^{\frac{1}{2}}f(x)$ belongs to $L^1(a, \infty)$, $a > 0$, then we define

$$T_1[f(x)] \equiv F(s)$$
$$= \int_a^\infty xC_\nu(xs, as)f(x)dx_1 \quad \ldots\ldots\ldots\ldots\ldots \text{(1.3)}$$

and, if $f(t)$ is of bounded variation near $t = x$,

$$\tfrac{1}{2}\{f(x+0) + f(x-0)\} = \int_0^{\to \infty} \frac{sC_\nu(xs, as)}{[Q_\nu(as)]^2}F(s)ds$$
$$\equiv T^{-1}[F(s)]. \quad \ldots\ldots\ldots\ldots \text{(1.4)}$$

When we say that " a function $h(t)$ belongs to $L^p(a, b)$ ", we mean that $h(t)$ is measurable, and $\int_a^b |h(t)|^p dt$ exists in the Lebesgue sense. By the notation $\int^{\to \infty} h(t)dt$, we understand $\lim_{\lambda \to \infty} \int^\lambda h(t)dt$ where the integral may or may not converge absolutely. When we write $\int^\infty h(t)dt$ we will know that the integral does converge absolutely as in equation (1.3) above.

The second type of the Weber transform is that in which the s-function (say $G(s)$) is the initial function. The theorems of [W.B.F] on p. 468 allow the derivation of a transform of this type. However, since these theorems demand that $G(s)$ should be zero in a neighbourhood of the origin, the transform derived from them is not sufficiently general for this paper. In the Appendix, we will prove a theorem, of which the following is an obvious corollary :

B_1 : If $\nu \geqq 0$, and $s^{\frac{1}{2}}G(s)/Q_\nu(as)$ belongs to $L^1(0, \infty)$, then we define

$$W_1[G(s)] \equiv g(x)$$
$$= \int_0^\infty \frac{sC_\nu(xs, as)}{[Q_\nu(as)]^2}G(s)ds \quad \ldots\ldots\ldots\ldots \text{(1.5)}$$

and, if $G(t)$ is of bounded variation near $t = s > 0$,

$$\tfrac{1}{2}\{G(s+0) + G(s-0)\} = \int_a^{\to \infty} xC_\nu(xs, as)g(x)dx$$
$$= W_1^{-1}[g(x)]. \quad \ldots\ldots\ldots\ldots \text{(1.6)}$$

If we use the properties of $C_\nu(xs, as)$ and $Q_\nu(as)$ mentioned in §2 of this paper, it will be clear that $F(s)$ defined by equation (1.3) and $g(x)$ defined by equation (1.5) will be continuous functions. However, it will be observed that since the inversion integrals do not necessarily converge absolutely, nothing is said concerning the L-class of $x^{\frac{1}{2}}g(x)$ or of $s^{\frac{1}{2}}G(s)/Q_\nu(as)$.

In §3, when we define the T_2-transform of a function $f(x)$ with $x^{\frac{1}{2}}f(x)$ belonging to $L^2(a, \infty)$, it will follow that if $F(s)=T_2[f(x)]$ then $s^{\frac{1}{2}}F(s)/Q_\nu(as)$ will belong to $L^2(a, \infty)$. A corresponding result will be found for the W_2-transform.

This will allow us to identify the T_2-transform with the W_2^{-1}-transform.

Now if we proceed formally, we may obtain the Parseval formula for the Weber Transforms. Thus

$$
\int_a^\infty xf(x)g(x)dx = \int_a^\infty xf(x)dx \int_0^\infty \frac{sC_\nu(xs, as)}{[Q_\nu(as)]^2}G(s)ds
$$

$$
= \int_0^\infty \frac{sG(s)}{[Q_\nu(as)]^2}ds \int_a^\infty xC_\nu(xs, as)f(x)dx.
$$

$$
= \int_0^\infty \frac{sF(s)G(s)}{[Q_\nu(as)]^2}ds.
$$

This formula will be shown to hold for the T_2-transform (and of necessity for the W_2-transform) without any further restrictions being placed on the functions concerned.

In §4, we will examine the T_2-transforms of functions which are zero outside a finite interval. Two theorems (or more accurately two different statements of the one theorem) will be proved. These theorems are of the type found in $[G]$, where the same problem was examined in the case of the Hankel J-transform.

2

This section contains some of the properties of certain of the functions, which will be used later in this paper.

(a) $C_\nu(\alpha, \beta) \equiv J_\nu(\alpha)Y_\nu(\beta) - J_\nu(\beta)Y_\nu(\alpha)$ (see equation (1.1)).

(i) $C_\nu(xz, az)$ is an analytic function of z if $x \geqq a > 0$.

To prove this assertion, we observe that $J_\nu(t)$ and $Y_\nu(t)$ have no singularities except at $t=0$. This point is a branch point.

If we use

$$
J_\nu(ze^{m\pi i}) = e^{m\nu\pi i}J_\nu(z)
$$

and

$$
Y_\nu(ze^{m\pi i}) = e^{-m\nu\pi i}Y_\nu(z) + 2i \sin m\nu\pi \cot \nu\pi J_\nu(z)
$$

(from [W.B.F.], p. 75), it follows immediately that $C_\nu(xz, az)$ is a single valued function of z.

In order to remove the singularity at the origin, it is necessary to define the value of $C_\nu(xz, az)$ at $z=0$ by $\lim_{z\to 0} C_\nu(xz, az)$. From the series expansions of the Bessel functions concerned, it is easy to derive

$$
C_\nu(xz, az) = -\frac{1}{\pi\nu}\left(\frac{x^\nu}{a^\nu} - \frac{a^\nu}{x^\nu}\right) + O(|z|^2), \qquad \nu \neq 0 \quad \ldots\ldots (2.1)
$$

as $|z| \to 0$, and

$$C_\nu(xz, az) = -\frac{2}{\pi} \ln \frac{x}{a} + O(|z|^2), \qquad \nu = 0 \quad \ldots \ldots \quad (2.2)$$

as $|z| \to 0$.

Thus we define

$$C_\nu(xz, az)_{z=0} = \begin{cases} -\dfrac{1}{\pi\nu}\left(\dfrac{x^\nu}{a^\nu} - \dfrac{a^\nu}{x^\nu}\right), & \nu > 0 \\[2mm] -\dfrac{2}{\pi} \ln \dfrac{x}{a}, & \nu = 0 \end{cases} \qquad \ldots \ldots \ldots \quad (2.3)$$

(ii) From the equations quoted above, we may also derive

$$C_\nu(\alpha e^{i\pi}, \beta e^{i\pi}) = C_\nu(\alpha, \beta), \quad \ldots \ldots \ldots \ldots \quad (2.4)$$

showing that $C_\nu(xz, az)$ is an even function of z for $x \geq a > 0$.

(iii) The asymptotic expansions of the Bessel functions give

$$C_\nu(xz, az) = \frac{2}{\pi z(ax)^{\frac{1}{2}}} \left\{ -\sin z(x-a) + \frac{4\nu^2-1}{8z}\left(\frac{1}{a} - \frac{1}{x}\right)\cos z(x-a) \right.$$

$$\left. + O(|z|)^{-2} e^{(x-a)|\operatorname{Im} z|} \right\} \quad \ldots \ldots \ldots \ldots \ldots \quad (2.5)$$

as $|z| \to \infty$.

(b) $E_\nu(\alpha, \beta) \equiv J_{\nu+1}(\alpha)Y_\nu(\beta) - J_\nu(\beta)Y_{\nu+1}(\alpha)$.

(i) By direct use of the formula $\dfrac{d}{dt}[t^{\nu+1}\mathbf{C}_{\nu+1}(t)] = t^{\nu+1}\mathbf{C}_\nu(t)$, where $\mathbf{C}_\nu(t)$ is any cylinder function, it follows that

$$\frac{d}{dx}\{x^{\nu+1}E_\nu(xs, as)\} = sx^{\nu+1}C_\nu(xs, as). \quad \ldots \ldots \ldots \ldots \quad (2.6)$$

(ii) The indefinite integral

$$\int zC_\nu(xz, az)dz = \frac{zxE_\nu(xz, az) + zaE_\nu(az, xz)}{x^2 - a^2} \quad \ldots \ldots \ldots \quad (2.7)$$

is obtained from [W.B.F.], p. 134 (8).

(iii) Formula (12) of [W.B.F.], p. 77, gives

$$E_\nu(\alpha, \alpha) = J_{\nu+1}(\alpha)Y_\nu(\alpha) - J_\nu(\alpha)Y_{\nu+1}(\alpha)$$

$$= \frac{2}{\pi\alpha}. \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (2.8)$$

(iv) The series definitions of the Bessel functions lead to

$$E_\nu(xz, az) = \frac{a_\nu}{\pi x^{\nu+1}} z^{-1} + O(|z|) \quad \ldots \ldots \ldots \ldots \quad (2.9)$$

as $|z| \to 0$.

(c) $[Q_\nu(\alpha)]^2 \equiv [J_\nu(\alpha)]^2 + [Y_\nu(\alpha)]^2$ (see equation (1.2)).

(i) $[Q_\nu(\alpha)]^2 = \dfrac{2}{\pi\alpha}[1+O(\alpha^{-2})]$ .... (2.10)

   as $\alpha \to \infty$.

(ii) $\begin{cases} \alpha^{2\alpha}[Q_\nu(\alpha)]^2 = \pi^{-2}2^{2\nu}[\Gamma(\nu)]^2 + o(1), & \nu > 0 \\ [\ln \alpha]^{-2}[Q_\nu(\alpha)]^2 = 4\pi^{-2} + o(1), & \nu = 0 \end{cases}$ .... (2.11)

   as $\alpha \to 0+$.

(d) The Bessel function of the third kind defined by $H_\nu^{(1)}(z) = J_\nu(z) + iY_\nu(z)$ has no singularities for $\mathrm{Im}\, z \geq 0$, and

(i) $\dfrac{H_\nu^{(1)}(xz)}{H_\nu^{(1)}(az)} = \dfrac{a^\nu}{x^\nu} + o(1)$ .... (2.12)

   as $|z| \to 0$;

(ii) $\dfrac{H_\nu^{(1)}(xz)}{H_\nu^{(1)}(az)} = a^{\frac{1}{2}}x^{-\frac{1}{2}}e^{iz(x-a)}\{1 + O(|z|^{-1})\}$ .... (2.13)

   as $|z| \to \infty$;

(iii) $\dfrac{H_{\nu+1}^{(1)}(xz)}{H_\nu^{(1)}(az)} = \dfrac{1}{z}\left\{ \dfrac{2\nu a^\nu}{x^{\nu+1}} + o(1) \right\}$ .... (2.14)

   as $|z| \to 0$;

(iv) $\dfrac{H_{\nu+1}^{(1)}(xz)}{H_\nu^1(az)} = -ia^{\frac{1}{2}}x^{-\frac{1}{2}}e^{iz(x-a)}\{1 + O(|z|^{-1})\}$ .... (2.15)

   as $|z| \to \infty$.

(e) As the unit function, we define

$$U(x) = \begin{cases} 1, & x > 0. \\ 0, & x < 0. \end{cases}$$ .... (2.16)

3

In this section, we define a T_2-transform, for functions which belong to an L^2-space. This transform will coincide with the T_1-transform when $f(x)$ is a function which satisfies Theorem A_1. The final results are stated in a theorem of the Plancherel type, Theorem 3.1.

Suppose that $x^{\frac{1}{2}}f(x)$ and $x^{\frac{1}{2}}g(x)$ belong to $L^2(a, \infty)$. Then, there exist approximating sequences $\{x^{\frac{1}{2}}f_n(x)\}$ and $\{x^{\frac{1}{2}}g_n(x)\}$ such that $x^{\frac{1}{2}}f_n(x)$ and $x^{\frac{1}{2}}g_n(x)$ are functions which are continuous over a finite interval and zero outside that interval, and

$$\lim_{n \to \infty} \int_a^\infty x[f(x) - f_n(x)]^2 dx = 0, \quad \ldots\ldots\ldots\ldots (3.1)$$

and

$$\lim_{n \to \infty} \int_a^\infty x[g(x) - g_n(x)]_z dx = 0. \quad \ldots\ldots\ldots\ldots (3.2)$$

Writing $F_n(s) = T_1[f_n(x)]$ and $G_n(s) = T_1[g_n(x)]$, we find that

$$\int_0^\lambda \frac{F_m(s)G_n(s)}{[Q_\nu(as)]^2} ds = \int_0^\lambda \frac{sF_m(s)}{[Q_\nu(as)]^2} ds \int_a^\infty xg_n(x)C_\nu(xs, as)dx$$

$$= \int_a^\infty xg_n(x)dx \int_0^\lambda \frac{sF_m(s)C_\nu(xs, as)}{[Q_\nu(as)]^2} ds.$$

The inversion of the order of integration is justified since the range of integration is actually finite and the integrand is continuous.

If we take the limit $\lambda \to \infty$, which is easily justified, see [T.T.F.], p. 390 (iv), and then use the inversion theorem in the form A_1, we obtain

$$\int_0^{\to \infty} \frac{sF_m(s)G_n(s)}{[Q_\nu(as)]^2} ds = \int_a^\infty xf_m(x)g_n(x)dx. \quad \dots\dots\dots \quad (3.3)$$

Thus we have

$$\int_0^\infty \frac{s[F_n(s)]^2}{[Q_\nu(as)]^2} ds = \int_a^\infty x[f_n(x)]^2 dx.$$

and

$$\int_0^\infty \frac{s[F_m(s) - F_n(s)]^2}{[Q_\nu(as)]^2} ds = \int_a^\infty x[f_m(x) - f_n(x)]^2 dx. \quad \dots\dots \quad (3.4)$$

Since the right side of equation (3.4) tends to zero when both m and n tend to infinity together, then so does the left side. Thus $\left\{\dfrac{s^{\frac{1}{2}}F_n(s)}{Q_\nu(as)}\right\}$ converges in the mean square to a function $\dfrac{s^{\frac{1}{2}}F(s)}{Q_\nu(as)}$ (say) which belongs to $L^2(0, \infty)$.

As a consequence, we make the definition

$$F(s) = T_2[f(x)]. \quad \dots\dots\dots\dots\dots \quad (3.5)$$

We have also obviously proved that

$$\int_0^\infty \frac{s[F(s)]^2}{[Q_\nu(as)]^2} ds = \lim_{n \to \infty} \int_0^\infty \frac{s[F_n(s)]^2}{[Q_\nu(as)]^2} ds$$

$$= \lim_{n \to \infty} \int_a^\infty x[f_n(x)]^2 dx$$

$$= \int_a^\infty x[f(x)]^2 dx. \quad \dots\dots\dots\dots \quad (3.6)$$

Now, in equation (3.6), we replace $f(x)$ by $f(x) + g(x)$ where both $x^{\frac{1}{2}}f(x)$ and $x^{\frac{1}{2}}g(x)$ belong to $L^2(a, \infty)$. Since the transform is obviously linear, we obtain

$$\int_0^\infty \frac{s[F(s) + G(s)]^2}{[Q_\nu(as)]^2} ds = \int_a^\infty x[f(x) + g(x)]^2 dx$$

and ultimately, after again using equation (3.6), arrive at the Parseval equation

$$\int_0^\infty \frac{sF(s)G(s)}{[Q_\nu(as)]^2} ds = \int_a^\infty xf(x)g(x)dx. \quad \dots\dots\dots \quad (3.7)$$

This result will be recorded later in Theorem 3B.

Now the definition of $F_n(s)$ written in full is

$$F_n(s) = \int_a^\infty x f_n(x) C_\nu(xs, as) dx$$

and then

$$\int_1^s \xi F_n(\xi) d\xi = \int_1^s d\xi \int_a^\infty x f_n(x) \xi C_\nu(x\xi, a\xi) dx \ \ldots \ (3.8)$$

where $s > 0$.

Since the range of integration is finite and all functions concerned are continuous, we may invert the order of integration and use equation (2.7) to obtain

$$\int_1^s \xi F_n(\xi) d\xi = \int_a^\infty x f_n(x) D_\nu(x, s) dx \ \ldots\ldots\ldots \ (3.9)$$

where

$$D_\nu(x, s) = \left[\frac{\xi x E_\nu(x\xi, a\xi) + \xi a E_\nu(a\xi, x\xi)}{x^2 - a^2} \right]_{\xi=1}^{\xi=s} \ \ldots\ldots \ (3.10)$$

All numerator terms of $D_\nu(x, s)$ are analytic functions of x for $s > 0$, and equation (2.8) shows that $D_\nu(x, s)$ is bounded as $x \to a$. Then, the asymptotic expansions of the Bessel Functions shows immediately that $x^{\frac{1}{2}} D_\nu(x, s)$ belongs to $L^2(a, \infty)$. We may thus take the limit $n \to \infty$ in equation (3.9).

So

$$\int_1^s \xi F(\xi) d\xi = \int_a^\infty x f(x) D_\nu(x, s) dx ; \ \ldots\ldots \ (3.11)$$

whence

$$F(s) = \frac{1}{s} \frac{d}{ds} \int_a^\infty x f(x) D_\nu(x, s) dx, \quad s > 0 \ .. \ (3.12)$$

almost everywhere.

The importance of equation (3.12) is that it shows that $F(s)$ is independent of the choice of the $\{f_n(x)\}$, and depends only on $f(x)$.

Now, it is clear that $x^{\frac{1}{2}} s C_\nu(xs, as)$, considered as a function of x, is uniformly bounded for $s \geq 0$. Thus, if $x^{\frac{1}{2}} f(x)$ belongs to $L^1(a, \infty)$, then the differentiation indicated in equation (3.12) can be carried out to show that, if $x^{\frac{1}{2}} f(x)$ belongs to both $L^1(a, \infty)$ and $L^2(a, \infty)$, then $T_1[f(x)] = T_2[f(x)]$.

If we now assume that $x^{\frac{1}{2}} f(x)$ belongs to $L^2(a, \infty)$, then $x^{\frac{1}{2}} f(x) U(p-x)$ belongs to both $L^2(a, \infty)$ and $L^1(a, \infty)$.

Then

$$F(s) - F(s, p) = T_2[f(x) U(x-p)],$$

where

$$F(s, p) = \frac{1}{s} \frac{d}{ds} \int_a^p x f(x) D_\nu(x, s) dx$$

$$= \int_a^p x f(x) C_\nu(xs, as) dx.$$

So equation (3.6) or (3.7) gives

$$\int_0^\infty \frac{s[F(s)-F(s,\ p)]^2}{[Q_\nu(as)]^2}ds = \int_p^\infty x[f(x)]^2dx$$
$$\longrightarrow 0,$$

as $p \to \infty$.

Now $\dfrac{s}{[Q_\nu(as)]^2} > 0$ for all $s > 0$. Thus

$$\lim_{p\to\infty}\int_0^\infty [F(s)-F(s,\ p)]^2ds = 0,$$

that is

$$F(s) = \text{l.i.m.}_{p\to\infty}\int_a^p xf(x)C_\nu(xs,\ as)dx. \quad \dots\dots\dots\dots \quad (3.13)$$

In order to obtain an inversion theorem, we write

$$g(x) \equiv g_\nu(x,\ \xi) = \begin{cases} x^\nu, & a < x < \xi, \\ 0, & x > \xi, \end{cases} \quad \dots\dots\dots \quad (3.14)$$

for which $x^{\frac{1}{2}}g(x)$ obviously belongs to both $L^1(a,\ \infty)$ and $L^2(a,\ \infty)$. The transform of $g_\nu(x,\ \xi)$ is

$$G_\nu(s,\ \xi) = T_2[g_\nu(x,\ \xi)]$$
$$= \int_a^\xi x^{\nu+1}C_\nu(xs,\ as)dx$$
$$= s^{-1}\left[\xi^{\nu+1}E_\nu(\xi s,\ as) - \frac{2a^\nu}{\pi s}\right] \quad \dots\dots\dots \quad (3.15)$$

(from equations (2.6) and (2.8)).

Therefore equation (3.7) gives

$$\int_a^\xi x^{\nu+1}f(x)dx = \int_0^\infty \frac{sF(s)G_\nu(s,\ \xi)}{[Q_\nu(as)]^2}ds,$$

that is

$$f(x) = \frac{1}{x^{\nu+1}}\frac{d}{dx}\int_0^\infty \frac{sF(s)G_\nu(s,\ x)}{[Q_\nu(as)]^2}ds \quad \dots\dots\dots \quad (3.16)$$

almost everywhere.

We may now summarize the results obtained up to this point by

A_2 : If $x^{\frac{1}{2}}f(x)$ belongs to $L^2(a,\ \infty)$ and $\{x^{\frac{1}{2}}f_n(x)\}$ is a sequence of functions which are continuous over a finite range and which are zero outside that range

and which approximate to $x^{\frac{1}{2}}f(x)$ in the mean, then there exists a function $F(s)$, such that

(a) $\dfrac{s^{\frac{1}{2}}F(s)}{Q_\nu(as)}$ belongs to $L^2(0,\ \infty)$

(b) $F(s)=\underset{n\to\infty}{\text{l.i.m}}\displaystyle\int_a^\infty xf_n(x)C_\nu(xs,\ as)dx$

(c) $\qquad=\underset{p\to\infty}{\text{l.i.m}}\displaystyle\int_a^p xf(x)C_\nu(xs,\ as)dx$

(d) $\qquad=\dfrac{1}{s}\dfrac{d}{ds}\displaystyle\int_a^\infty xf(x)D_\nu(x,\ s)dx$

(e) $f(x)=\dfrac{1}{x^{\nu+1}}\dfrac{d}{dx}\displaystyle\int_0^\infty \dfrac{sF(s)G_\nu(s,\ x)}{[Q_\nu(as)]^2}ds,$ almost everywhere.

We have thus defined a mapping of the whole set of functions $f(x)$ for which $x^{\frac{1}{2}}f(x)$ belongs to $L^2(a,\ \infty)$ on to a subset of the functions $F(s)$ for which $\dfrac{s^{\frac{1}{2}}F(s)}{Q_\nu(as)}$ belongs to $L^2(0,\ \infty)$.

In order to show that this subset is actually the whole set of $F(s)$ for which $\dfrac{s^{\frac{1}{2}}F(s)}{Q_\nu(as)}$ belongs to $L^2(0,\ \infty)$, we use the Theorem B_1. The procedure corresponds very closely to that just given. The conclusion will be

B_2: If $s^{\frac{1}{2}}F(s)/Q_\nu(as)$ belongs to $L^2(0,\ \infty)$ and $\{s^{\frac{1}{2}}F_n(s)/Q_\nu(as)\}$ is a sequence of functions which are continuous over a finite range and which are zero outside that range and which converges to $s^{\frac{1}{2}}F(s)/Q_\nu(as)$ in the mean, then there exists a function $f(x)$ such that

(a) $x^{\frac{1}{2}}f(x)$ belongs to $L^2(a,\ \infty)$,

(b) $f(x)=\underset{n\to\infty}{\text{l.i.m}}\displaystyle\int_0^\infty \dfrac{sF_n(s)C_\nu(xs,\ as)}{[Q_\nu(as)]^2}ds,$

(c) $\qquad=\underset{p\to\infty}{\text{l.i.m}}\displaystyle\int_0^p \dfrac{sF(s)C_\nu(xs,\ as)}{[Q_\nu(as)]^2}ds,$

(d) $\qquad=\dfrac{1}{x^{\nu+1}}\dfrac{d}{dx}\displaystyle\int_0^\infty \dfrac{sF(s)G_\nu(s,\ x)}{[Q_\nu(as)]^2}ds,$

(e) $F(s)=\dfrac{1}{s}\dfrac{d}{ds}\displaystyle\int_a^\infty xf(x)D_\nu(x,\ s)dx,$ almost everywhere.

The only point worthy of note in the derivation of B_2 is that the function which replaces $g_\nu(x,\ \xi)$ in equation (3.14) would be

$$H(s,\ \xi)=\begin{cases}[Q_\nu(as)], & 1<s<\xi \\ 0 & \text{otherwise}\end{cases}\Bigg\}\,\xi<1.$$

$$\qquad=\begin{cases}-[Q_\nu(as)]^2, & \xi<s<1 \\ 0 & \text{otherwise}\end{cases}\Bigg\}\,\xi<1.$$

Comparing A_2 and B_2, we are able to enunciate.

Theorem 3.1.

To every $f(x)$ for which $x^{\frac{1}{2}}f(x)$ belongs to $L^2(a, \infty)$, there corresponds a unique function $F(s)$, for which $s^{\frac{1}{2}}F(s)/Q_\nu(as)$ belongs to $L^2(0, \infty)$ (and conversely). The functions $f(x)$ and $F(s)$ are connected by the formulae

(a) $F(s) \equiv T_2[f(x)] \equiv W_2^{-1}[f(x)]$

(b) $\qquad = \underset{p \to \infty}{\text{l.i.m}} \int_a^p xf(x)C_\nu(xs, as)dx$

(c) $\qquad = \dfrac{1}{s} \dfrac{d}{ds} \int_a^\infty xf(x)D_\nu(x, s)dx.$

(d) $f(x) \equiv T_2^{-1}[F(s)] \equiv W_2[F(s)],$

(e) $\qquad = \underset{p \to \infty}{\text{l.i.m}} \int_0^p \dfrac{sF(s)C_\nu(xs, as)}{[Q_\nu(as)]^2}ds$

(f) $\qquad = \dfrac{1}{x^{\nu+1}} \dfrac{d}{dx} \int_0^\infty \dfrac{sF(s)G_\nu(s, x)}{[Q_\nu(as)]^2}ds.$

Also corresponding to equation (3.7), we have

Theorem 3.2.

If $F(s) = T_2[f(x)]$, and $G(s) = T_2[g(x)]$, then

$$\int_a^\infty xf(x)g(x)dx = \int_0^\infty \dfrac{sF(s)G(s)}{[Q_\nu(as)]^2}ds.$$

4

In this section, we examine the transform of a function which is zero outside a finite interval. If we suppose that $g(x) = 0$ for $x > b$, then

$$\begin{aligned} G(s) &= T_2[g(x)] \\ &= T_1[g(x)] \\ &= \int_a^b xC_\nu(xs, as)g(x)dx \end{aligned} \quad \ldots\ldots\ldots\ldots (4.1)$$

and we may define

$$G(z) = \int_a^b xC_\nu(xz, az)g(x)dx \quad \ldots\ldots\ldots\ldots (4.2)$$

where $z = s + i\beta$.

Then, assuming that $C_\nu(xz, az)_{z=0}$ is defined by equation (2.3), we see that $G(z)$ will be defined for $z = 0$.

There are two forms of the theorem. If $G(z)$ is considered to be defined in whole z-plane we have

Theorem 4.1.

In order that $x^{\frac{1}{2}}g(x)$ belongs to $L^2(a, \infty)$ and

$$g(x) = 0, \text{ for } x > b > a, \quad \ldots\ldots\ldots\ldots (4.3)$$

it is necessary and sufficient that

(i) $s^{\frac{1}{2}}G(s)/Q_\nu(as)$ belongs to $L^2(0, \infty)$;
(ii) $G(z)$ is analytic in $z=s+i\beta$ for all z ;
(iii) $G(ze^{i\pi})=G(z)$;
(iv) $|zG(z)|=O(e^{(b-a)|\beta|})$, as $|z|\to\infty$.

If it is preferred to consider $G(z)$ defined in the half-plane $\beta\geq0$, then the enunciation is

Theorem 4.2.

In order that $x^{\frac{1}{2}}g(x)$ belongs to $L^2(a, \infty)$ and

$$g(x)=0 \text{ for } x>b>a,$$

it is necessary and sufficient that

(ia) $s^{\frac{1}{2}}G(s)/Q_\nu(as)$ belongs to $L^2(0, \infty)$;
(iia) $G(z)$ is analytic in $z=s+i\beta$ for $\beta\geq0$;
(iiia) $G(se^{i\pi})=G(s)$, for real s ;
(iva) $|zG(z)|=O(e^{(b-a)\beta})$, as $|z|\to\infty$, $\beta\geq0$.

It is easy to see that the set (i)-(iv) implies (ia)-(iva) and conversely. We prove the theorem in the form 4.1.

Proof.
Necessary Conditions.

Theorem 3.1 gives (ia) immediately.

Since $x^{\frac{1}{2}}g(x)$ belongs to $L^2(a, b)$, it belongs to $L^1(a, b)$, and since as was shown in §2 (a) (i), $x^{\frac{1}{2}}C_\nu(xz, az)$ is an analytic function of z ; (iia) is obvious.

Now

$$G(se^{i\pi})=\int_a^b xC_\nu(xse^{i\pi}, ase^{i\pi})g(x)dx$$

$$=\int_a^b xC_\nu(xs, as)g(x)dx$$

(by equation (2.4))

$$=G(z),$$

which proves (iiia).

Now to prove (iva), we use §2 (a) (iii), which shows that, provided $|z|$ is taken sufficiently large,

$$|G(z)|<A\int_a^b x^{\frac{1}{2}}|g(x)|\frac{e^{(x-a)\beta}}{|z|}dx, \text{ for some constant A} ;$$

$$<A|z|^{-1}e^{(b-a)\beta}\int_a^b x^{\frac{1}{2}}|g(x)|dx,$$

that is

$$|zG(z)|=O(e^{(b-a)\beta})$$

as $|z|\to\infty$.

Sufficient Conditions.

Now in order to prove the converse, we assume that (i*a*)-(i*va*) hold. This method follows the lines of [*G*]. We will prove that

$$T_2[g(x)] = T_2[g(x) U(p-x)] \quad \text{for all } p > b, \quad \ldots\ldots\ldots \quad (4.4)$$

then, using the inversion theorem 3.1, we will obtain

$$g(x) = g(x) U(p-x), \quad \text{for all } p > b, \quad \ldots\ldots\ldots\ldots \quad (4.5)$$

that is

$$g(x) = 0, \quad \text{for } x > b \quad \ldots\ldots\ldots\ldots\ldots \quad (4.6)$$

(we, of course, identify functions which are equal almost everywhere).

We write

$$
\begin{aligned}
P(s, t, p) &= T_2[C_\nu(xt, at) U(p-x)] \\
&= \int_a^p x C_\nu(xs, as) C_\nu(xt, at) dx \\
&= \frac{p}{s^2 - t^2} \{ s E_\nu(ps, as) C_\nu(pt, at) - t E_\nu(pt, at) C_\nu(ps, as) \},
\end{aligned}
$$

where $E_\nu(\alpha, \beta)$ has been defined in §2 (*b*).

Then the Parseval Theorem 3.2 gives

$$\int_0^\infty \frac{tP(t, s, p)G(t)}{[Q_\nu(at)]^2} dt = \int_a^\infty x C_\nu(xs, as) U(p-x) g(x) dx,$$

which can be interpreted as

$$\int_0^\infty \frac{tP(t, s, p)G(t)}{[Q_\nu(at)]^2} dt = T_2[g(x) U(p-x)], \quad \ldots\ldots\ldots\ldots \quad (4.7)$$

We will show that the left side of equation (4.7) equals $G(s)$, if (i*a*)-(i*va*) hold.

It will be convenient to write $z = t + i\beta$, and consider the integral

$$\int \frac{pzG(z)}{z^2 - s^2} \left\{ \frac{zH_{\nu+1}^{(1)}(pz)}{H_\nu^{(1)}(az)} C_\nu(ps, as) - \frac{sH_\nu^{(1)}(pz)}{H_\nu^{(1)}(az)} E_\nu(ps, as) \right\} dz, \quad \ldots \quad (4.8)$$

taken over the contour shown in the figure.
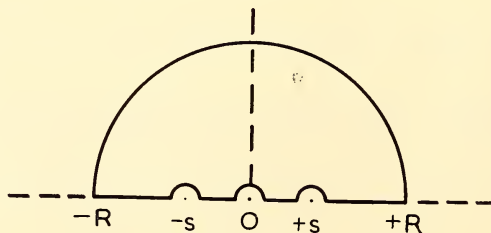
The semi-circles above $z = +s$, $z = -s$ and $z = 0$ are assumed to have the same radius ε, and the large semi-circle is assumed to have radius R. In the final step the limits $\varepsilon \to 0$ and $R \to \infty$ are taken.

Since $H_\nu^{(1)}(az)$ has no zeros above the real axis, the integral vanishes by Cauchy's Theorem.

Since $G(z)$ is analytic near $z=0$, it is bounded there. Then §2 (d) (i) and (iii) show that the contribution due to the semi-circle at the origin vanishes in the limit.

If we adopt the usual notation $H_\nu^{(2)}(z)=J_\nu(z)-iY_\nu(z)$, we find from [W.B.F.] p. 75, that when t is real,

$$H_\nu^{(1)}(te^{i\pi})=-e^{-\nu\pi i}H_\nu^{(2)}(t). \quad \dots\dots\dots\dots (4.9)$$

This result and assumption (iiia) allows us to show that the contribution from the real axis is

$$\int_{\to 0}^{\to\infty} \frac{pt^2G(t)}{t^2-s^2}\left[\frac{H_{\nu+1}^{(1)}(pt)}{H_\nu^{(1)}(at)}-\frac{H_{\nu+1}^{(2)}(pt)}{H_\nu^{(2)}(at)}\right]C_\nu(ps,as)dt$$

$$-\int_{\to 0}^{\to\infty} \frac{pst}{t^2-s^2}\left[\frac{H_\nu^{(1)}(pt)}{H_\nu^{(1)}(at)}-\frac{H_\nu^{(2)}(pt)}{H_\nu^{(2)}(at)}\right]E_\nu(ps,as)dt$$

$$=-2i\int_0^\infty \frac{tP(t,s,p)G(t)}{[Q_\nu(at)]^2}dt.$$

The points $z=\pm s$ are poles of the integrand and the contribution due to the semi-circles above $z=\pm s$ is

$$-\pi ip\left[\tfrac{1}{2}G(s)\left\{\frac{sH_{\nu+1}^{(1)}(ps)}{H_\nu^{(1)}(as)}C_\nu(ps,as)-\frac{sH_\nu^{(1)}(ps)}{H_\nu^{(1)}(as)}E_\nu(ps,as)\right\}\right.$$

$$\left.+\tfrac{1}{2}G(s)\left\{\frac{sH_{\nu+1}^{(2)}(ps)}{H_\nu^{(2)}(as)}C_\nu(ps,as)-\frac{sH_\nu^{(2)}(ps)}{H_\nu^{(2)}(as)}E_\nu(ps,as)\right\}\right]$$

$$=-\frac{\pi ipsG(s)}{[Q_\nu(as)]^2}[C_\nu(ps,as)\{J_{\nu+1}(ps)J_\nu(as)+Y_{\nu+1}(ps)Y_\nu(as)\}$$

$$-E_\nu(ps,as)\{J_\nu(ps)J_\nu(as)+Y_\nu(ps)Y_{\nu+1}(as)\}]. \quad \dots\dots\dots (5.10)$$

If we expand the expression in square brackets and regroup the terms, we find that this contribution is equal to

$$\left\{\frac{\pi ipsG(s)}{[Q_\nu(as)]^2}\right\}\{[Q_\nu(as)]^2E_\nu(ps,ps)\}$$

$$=\pi ipsG(s)\left(\frac{2}{\pi ps}\right)$$

$$=2iG(s).$$

In the simplification we have used equation (2.8).

If we now use §2 (d) (ii) and (iv) together with assumption (iva) we find that the integrand is $O(|z|^{-1}e^{-\beta(p-b)})$ on the large semi-circle. Then applying the Lemma of §3 of [G] we see that the integral taken along this large semi-circle vanishes when $R\to\infty$ for $p>b$.

Thus, combining our results, we have

$$-2i\int_0^\infty \frac{tP(t,\,s,\,p)G(t)}{[Q_\nu(at)]^2}dt+2iG(s)=0,$$

that is

$$\int_0^\infty \frac{tP(t,\,s,\,p)G(t)}{[Q_\nu(at)]^2}dt=G(s), \quad p>b,$$

which is the required result and the theorem is proved.

APPENDIX.

In this appendix, we prove a theorem from which the transform W_1 and its inverse may be derived.   A theorem of this type is found in [W.B.F.], p. 468 *et seq.*   This theorem of Watson is most unsuitable for our purpose since it demands that $F(s)$ must be zero in a neighbourhood of the origin and the restrictions on $F(s)$, for $s\to\infty$, are somewhat too heavy.

The theorem we will prove will be :

Theorem W.

Assuming that $\nu\geqq0$, $s^{\frac{1}{2}}F(s)/Q_\nu(as)$ belongs to $L^1(0,\,\infty)$ and that $F(s)$ is of bounded variation near the point $s=u$, then $\frac{1}{2}\{F(u+0)+F(u-0)\}$

$$=\int_a^{\to\infty} xC_\nu(xu,\,au)dx\int_0^\infty \frac{sF(s)C_\nu(xs,\,as)}{[Q_\nu(as)]^2}ds. \quad \dots\dots\dots \text{(A.1)}$$

Proof.

By equations (2.1) and (2.2), $s^{\frac{1}{2}}C_\nu(xs,\,as)/Q_\nu(as)$ is uniformly bounded for $a\leqq x\leqq\lambda$.   Thus $\displaystyle\int_0^\infty sC_\nu(xs,\,as)F(s)/[Q_\nu(as)]^2ds$ converges uniformly for $a\leqq x\leqq\lambda$. So we multiply by $xC_\nu(xu,\,au)$ and integrate under the integral sign to obtain

$$\int_a^\lambda xC_\nu(xu,\,au)dx\int_0^\infty \frac{sF(s)C_\nu(xs,\,as)}{[Q_\nu(as)]^2}ds$$

$$=\int_0^\infty \frac{sF(s)ds}{[Q_\nu(as)]^2}\int_a^\lambda xC_\nu(xu,\,au)C_\nu(xs,\,as)dx \quad \dots\dots\dots\dots \text{(A.2)}$$

$$=\int_0^\infty \frac{sF(s)}{[Q_\nu(as)]^2}\Big\{\frac{\lambda}{s^2-u^2}[sE_\nu(\lambda s,\,as)C_\nu(\lambda u,\,au)-uE_\nu(\lambda u,\,au)C_\nu(\lambda s,\,as)]\Big\}ds.$$

$$\dots\dots\dots\dots\dots\dots \text{(A.3)}$$

Thus our theorem is proved, if we can prove that
$\frac{1}{2}\{F(u+0)+F(u-0)\}$

$$=\lim_{\lambda\to\infty}\int_0^\infty \frac{sF(s)}{[Q_\nu(as)]^2}\Big\{\frac{\lambda}{s^2-u^2}[sE_\nu(\lambda s,\,as)C_\nu(\lambda u,\,au)-uE_\nu(\lambda u,\,au)C_\nu(\lambda s,\,as)]\Big\}ds$$

$$\dots\dots\dots\dots\dots \text{(A.4)}$$

For this purpose we split the range of integration into

$$\int_0^\infty = \int_0^\eta + \int_\eta^{u-\delta} + \int_{u-\delta}^{u+\delta} + \int_{u+\delta}^\infty . \qquad \cdots\cdots\cdots \quad (A.5)$$

Now the integrand in equation (A.4) can be expanded in the form

$$\frac{s^{\frac{1}{2}}F(s)}{Q_\nu(as)} \cdot \frac{\lambda s^{\frac{1}{2}}}{s^2-u^2} \left\{ s\left[J_{\nu+1}(\lambda s)\frac{Y_\nu(as)}{Q_\nu(as)} - J_\nu(as)\frac{Y_{\nu+1}(\lambda s)}{Q_\nu(as)} \right][J_\nu(\lambda u)Y_\nu(au) - J_\nu(au)Y_\nu(\lambda u)] \right.$$

$$\left. -u[J_{\nu+1}(\lambda u)Y_\nu(au) - Y_{\nu+1}(\lambda u)J_\nu(au)]\left[J_\nu(\lambda s)\frac{Y_\nu(as)}{Q_\nu(as)} - J_\nu(as)\frac{Y_\nu(\lambda s)}{Q_\nu(as)} \right] \right\},$$

from which we observe that the factor following the point is bounded for all s and λ. Thus we can make the contribution from $\int_0^\eta$ arbitrarily small by choosing η sufficiently small. We now consider this done.

The contribution from the integral $\int_\eta^{u-\delta}$ may be written as the sum of eight integrals of the form

$$\int_\eta^{u-\delta} \frac{s^{\frac{1}{2}}F(s)}{Q_\nu(as)} H_i(s)P_i(s,\lambda)ds, \qquad \cdots\cdots\cdots\cdots \quad (A.6)$$

where the $H_i(s)$ are bounded functions of s (independent of λ), and $P_i(s,\lambda)$ is one of the functions $\lambda J_{\nu+1}(\lambda s)J_\nu(\lambda u)$, $\lambda J_{\nu+1}(\lambda s)Y_\nu(\lambda u)$, $\lambda Y_{\nu+1}(\lambda s)J_\nu(\lambda u)$, $\lambda Y_{\nu+1}(\lambda s)Y_\nu(\lambda u)$, $\lambda J_\nu(\lambda s)J_{\nu+1}(\lambda u)$, $\lambda J_\nu(\lambda s)Y_{\nu+1}(\lambda u)$, $\lambda Y_\nu(\lambda s)J_{\nu+1}(\lambda u)$, $\lambda Y_\nu(\lambda s)Y_{\nu+1}(\lambda u)$.

Each of these integrals will vanish as $\lambda\to\infty$. Since the method of proof is the same for each, we will prove this for the first.

If we use the usual notation $\omega_\nu=\frac{1}{2}\nu\pi+\frac{1}{4}\pi$, the asymptotic expansions of the Bessel Functions show that this integral may be written as

$$\int_\eta^{u-\delta} A(s)\left\{ \sin(\lambda s - \omega_\nu)\cos(\lambda u - \omega_\nu) + O\left(\frac{1}{\lambda}\right)\right\}ds, \qquad \cdots \quad (A.7)$$

where obviously $A(s)$ belongs to $L^1(\eta, u-\delta)$. The Riemann-Lebesgue theorem for Fourier integrals ([T.F.I.], p. 11, Th. 1) shows immediately that this integral vanishes as $\lambda\to\infty$.

By a similar argument, the contributions, due to integrals of the form

$$\int_{u+\delta}^\infty \frac{s^{\frac{1}{2}}F(s)}{Q_\nu(as)} H_i(s)P_i(s,\lambda)ds,$$

also vanish for $\lambda\to\infty$.

Now considering the integral $\int_{u-\delta}^{u+\delta}$ and supposing that λ is sufficiently large, we may write the contribution as

$$\frac{2}{\pi}\int_{u-\delta}^{u+\delta}\frac{sF(s)}{[Q_\nu(as)]^2}\frac{1}{s^2-u^2}.$$

$$\left\{J_\nu(as)J_\nu(au)\left[-\frac{s^{\frac12}}{u^{\frac12}}\cos(\lambda s-\omega_\nu)\sin(\lambda u-\omega_\nu)+\frac{u^{\frac12}}{s^{\frac12}}\sin(\lambda s-\omega_\nu)\cos(\lambda u-\omega_\nu)\right]\right.$$

$$+Y_\nu(as)Y_\nu(au)\left[\frac{s^{\frac12}}{u^{\frac12}}\sin(\lambda s-\omega_\nu)\cos(\lambda u-\omega_\nu)-\frac{u^{\frac12}}{s^{\frac12}}\cos(\lambda s-\omega_\nu)\sin(\lambda u-\omega_\nu)\right]$$

$$+Y_\nu(as)J_\nu(au)\left[-\frac{s^{\frac12}}{u^{\frac12}}\sin(\lambda s-\omega_\nu)\sin(\lambda u-\omega_\nu)-\frac{u^{\frac12}}{s^{\frac12}}\cos(\lambda s-\omega_\nu)\cos(\lambda u-\omega_\nu)\right]$$

$$+J_\nu(as)Y_\nu(au)\left[\frac{s^{\frac12}}{u^{\frac12}}\cos(\lambda s-\omega_\nu)\cos(\lambda u-\omega_\nu)+\frac{u^{\frac12}}{s^{\frac12}}\sin(\lambda s-\omega_\nu)\sin(\lambda u-\omega_\nu)\right]$$

$$\left.+O\left(\frac{1}{\lambda}\right)\right\}ds$$

$$=\frac{1}{\pi}\int_{u-\delta}^{u+\delta}\frac{s^{\frac12}F(s)}{u^{\frac12}[Q_\nu(as)]^2}\left\{J_\nu(as)J_\nu(au)\left[\frac{\sin\lambda(s-u)}{s-u}-\frac{\sin\{\lambda(s+u)-2\omega_\nu\}}{s+u}\right]\right.$$

$$+Y_\nu(as)Y_\nu(au)\left[\frac{\sin\lambda(s-u)}{s-u}+\frac{\sin\{\lambda(s+u)-2\omega_\nu\}}{s+u}\right]$$

$$+\frac{J_\nu(as)Y_\nu(au)-Y_\nu(as)J_\nu(au)}{s^2-u^2}(s^2+u^2)\cos\lambda(s-u)$$

$$+[J_\nu(as)Y_\nu(au)+Y_\nu(as)J_\nu(au)]\cos\{\lambda(s+u)-2\omega_\nu\}$$

$$\left.+O\left(\frac{1}{\lambda}\right)\right\}ds.$$

Now if we apply the Riemann-Lebesgue Theorem we see that we may neglect all terms which do not contain $\dfrac{\sin\lambda(x-u)}{x-u}$ as a factor.

Then considering the remaining terms, we use Fourier's single integral formula ([T.F.I.], p. 25, Th. 12) and obtain as the contribution from $\int_{u-\delta}^{u-\delta}$,

$$\tfrac12\{F(u+0)+F(u-0)\}$$

and the theorem is proved.

REFERENCES.

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[T.T.F]   ——————   " Theory of Functions." Oxford, 1939.
[T.F.I.]   ——————   " Fourier Integrals." Oxford, 1948.
[W.B.F.]   Watson, G. N. " Theory of Bessel Functions." Cambridge, 1945.
[G]   Griffith, J. L., 1955. "Hankel Transforms of Functions Zero outside a Finite Interval." THIS JOURNAL, , 89, 109.

ABSTRACT OF PROCEEDINGS.

April 6th, 1955.

The seven hundred and tenth Annual and General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

Dr. Ida A. Browne, Vice-President, was in the chair. Thirty-six members and visitors were present. The minutes of the previous meeting were read and confirmed.

The following deaths were announced : Gordon Kingsley Hughes, a member since 1938. Martin Raphael Freney, a member since 1940.

The certificates of four candidates for admission as ordinary members of the Society were read for the first time.

The certificates of two candidates were read for the second time, and the following persons were duly elected members of the Society : Jean Norma Colville and Lothar Max Mandl.

It was announced that the Clarke Memorial Lectureship for 1955 had been awarded to Mr. R. O. Chalmers of the Australian Museum.

Awards.—It was announced that the Society's awards were as follows : The Society's Medal for 1954 was made to Dr. D. P. Mellor. The James Cook Medal for 1954 was made to Sir Frank Macfarlane Burnet, F.R.S. The Edgeworth David Medal for 1954 was made to Dr. E. S. Barnes. The Clarke Medal for 1955 was made to Dr. R. N. Robertson.

Annual Report.—The Annual Report of the Council was presented and adopted.

Financial Statement.—The Financial Statement was presented and adopted.

Election of Auditors.—Messrs. Horley and Horley were re-elected as Auditors to the Society for 1955–56.

Library.—The following donations were received : parts of periodicals, 435 ; purchased parts, 32 ; back numbers, 38.

The following papers were read by title only :

" The Essential Oil of *Backhousia myrtifolia* Hooker *et* Harvey. Part III. Single-tree Studies on Physiological Forms from Queensland ", by R. O. Hellyer, H. H. G. McKern and J. L. Willis.

" Occultations Observed at Sydney Observatory during 1954 ", by K. P. Sims, B.Sc.

" On Some Species of Phyllotheca ", by John A. Townrow.

The following were elected Office-Bearers for 1955–56 :

President : M. R. Lemberg, D.Phil., F.R.S.

Vice-Presidents : R. C. L. Bosworth, M.Sc., D.Sc. (Adel.), Ph.D. (Camb.), F.A.C.I., F.Inst.P. ; Ida A. Browne, D.Sc. ; F. D. McCarthy, Dip.Anthr. ; C. J. Magee, D.Sc.Agr. (Syd.), M.Sc. (Wis.).

Hon. Secretaries : J. L. Griffith, B.A., M.Sc., Dip.Ed. ; F. N. Hanlon, B.Sc.

Hon. Treasurer : H. A. J. Donegan, M.Sc., A.S.T.C., A.A.C.I.

Members of Council : Rev. T. N. Burke-Gaffney, S.J. ; D. P. Craig, Ph.D. ; F. P. J. Dwyer, D.Sc. ; H. O. Fletcher ; N. A. Gibson, M.Sc., Ph.D., A.R.I.C. ; A. F. A. Harper, M.Sc., A.Inst.P. ; P. R. McMahon, M.Agr.Sc. (N.Z.), Ph.D. (Leeds), A.R.I.C., A.N.Z.I.C. ; G. D. Osborne, D.Sc. (Syd.), Ph.D. (Camb.), F.G.S. ; J. S. Proud, B.E., M.(Aust.)I.M.M., A.M.I.E. ; Griffith Taylor, D.Sc., B.E., B.A.

Dr. D. P. Mellor presented the Presidential Address of the retiring President, Professor R. S. Nyholm, who had departed for England. The title of the address was " Magnetism and Stereochemistry ".

At the conclusion of the address the Chairman welcomed Dr. M. R. Lemberg, F.R.S., to the Presidential Chair.

May 4th, 1955.

The seven hundred and eleventh General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. M. R. Lemberg, F.R.S., was in the chair. Sixty-five members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificates of three candidates for admission as ordinary members were read for the first time.

The certificates of four candidates were read for the second time and the following persons were duly elected members of the Society : Ian Gavin Stuart Campbell, Leslie A. Denton, Norma F. Denton, Joan Audrey Marsden.

Members were requested to inform the office of the Society of any further degrees, distinctions or qualifications which should be added to their names appearing in the List of Members, also any changes of address.

Authors of papers appearing in the Society's Journal for 1943 and 1944 were advised that any stocks of reprints of their papers are available gratis and should be picked up not later than 15th June, 1955.

Library.—The following donations were received : parts of periodicals, 146 ; purchased parts, 29.

The following papers were read by title only :

" Ilmenite from Beach Sands of New South Wales ", by C. E. Curnow and L. G. Parry.

" The Occurrence and Genesis of Pyrrhotite and Chalcopyrite in Sediments near Rockley, New South Wales ", by R. L. Stanton.

" Distribution of Lower Cretaceous Foraminifera in Bores in the Great Artesian Basin, New South Wales ", by Irene Crespin.

The evening was devoted to the screening of the following films : " Power for the Highlands ". This film deals with the planning of the hydro-electric schemes in Scotland and was shown through the courtesy of the New South Wales Film Council. " Packaged Power." This film concerns the Kitimat Hydro-Electric Scheme, Canada. It won the award of the best industrially sponsored film in 1951, and was shown through the courtesy of the Australian Aluminium Co. Pty. Ltd. " Wealth from Water." This film deals with the Snowy Mountains Hydro-Electric Scheme and was shown through the courtesy of the Snowy Mountains Hydro-Electric Authority.

June 1st, 1955.

The seven hundred and twelfth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. M. R. Lemberg, F.R.S., was in the chair. Fifty-two members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificates of three candidates for admission as ordinary members were read for the first time.

The certificates of three candidates were read for the second time and the following persons were duly elected members of the Society : Austin Keane, Francis John Moss, Geraldine Lesley Thorley.

Clarke Memorial Lecture.—It was announced that the Clarke Memorial Lecture for 1955 would be delivered by Mr. R. O. Chalmers, Curator of Minerals and Rocks at the Australian Museum, on Thursday, June 16th, at 8 p.m., in the Hall of Science House, and would be entitled " Some Aspects of New South Wales Gemstones ".

Library.—The following donations were received : parts of periodicals, 220 ; purchased parts, 20 ; back numbers, 4.

The following paper was read by title only :

" Minor Planets Observed at Sydney Observatory during 1954 ", by W. H. Robertson.

The evening was devoted to a symposium on New Guinea. The following addresses were given :

" New Guinea and Its Peoples ", by Professor A. P. Elkin of the Department of Anthropology, the University of Sydney.

" Dental and General Health in New Guinea-Papua ", by Dr. N. E. Goldsworthy, Director of the Institute of Dental Research at the Dental Hospital of Sydney.

" Some Aspects of Agricultural Development—Papua and New Guinea ", by Mr. W. Cottrell-Dormer, Regional Agricultural Officer, Samarai, Territory of Papua and New Guinea.

" Some Factors in New Guinea's History ", by Mr. J. A. Miles of the Australian School of Pacific Administration.

July 6th, 1955.

The seven hundred and thirteenth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. M. R. Lemberg, F.R.S., was in the chair. Fifty-four members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificates of two candidates for admission as ordinary members were read for the first time.

The certificates of three candidates were read for the second time and the following persons were duly elected members of the Society : Edwin John Crawford, Ethel Beatrice Durie, Thomas Arthur Lang.

The President reported that the Clarke Memorial Lecture, held June 16th, had been most successful, the attendance being 170.

The following announcement was made : "That Council approves that the Section of Geology holds its meetings bi-monthly and alternatively with bi-monthly meetings of the Geological Society of Australia and that each Society gives notice of the other Society's meetings on its notice paper for General Monthly Meetings."

The following resignations from membership of the Society were announced : G. G. Blake, R. A. Crane, A. J. Gibson, C. M. Davison, G. O. Lowenbein, J. J. Veevers and R. E. Winchester.

Library.—The following donations were received : parts of periodicals, 190 ; purchased parts, 23.

The following paper was summarized by the author :

" Hankel Transforms of Functions Zero Outside a Finite Interval ", by J. L. Griffith, B.A., M.Sc.

The following papers were read by title only : ·

" The Geology of the Queanbeyan District ", by June R. Phillips, B.Sc.

" Pleistocene Glaciation and the Gray Mare Range ", by A. S. Ritchie and J. N. Jennings.

The evening was devoted to a commemoration of the late Albert Einstein, and the following addressed the audience : Dr. Ilse Rosenthal-Schneider, who was a friend and student of Einstein. She contributed to Volume 7 of the Library of Living Philosophers containing Einstein's " intellectual autobiography " and " a series of articles written by leading exponents and opponents " of his thought. Professor V. A. Bailey, Research Professor in the School of Physics, University of Sydney, who was recipient of the Walter Burfitt Prize, 1935, and the T. K. Sidey Medal and Prize, 1951. Professor Bailey visited the U.S.A. as a Visiting Professor at Pennsylvania State University, where he did research work in the Ionosphere Research Laboratory, 1953–54. He was recently elected to Fellowship of the Australian Academy of Science. Mr. J. B. Thornton had also been invited to speak, but owing to illness was unable to do so.

August 3rd, 1955.

The seven hundred and fourteenth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. M. R. Lemberg, F.R.S., was in the chair. Thirty-seven members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificates of three candidates for admission as ordinary members were read for the first time.

The certificate of one candidate was read for the second time and the following person was elected a member of the Society : Ian Andrew Crawford.

The following announcements were made : (1) Medical books as per list on the Hall table were for free disposal to members and would be available from the Library until Wednesday, August 17th, 1955. (2) The Library had recently commenced receiving regularly the following periodicals : Acta Geologica Polonica ; Grenoble Universite, Institute Fourier, Annales ; Kyoto Technical University, Faculty of Industrial Arts, Memoirs B., Science and Technology ; Sociedad Cubana de Ciencias Fisicas y Matematicas, Revista ; Tohoku University, Institute of High Speed Mechanics, Reports. (3) The Nuffield Foundation Dominion Travelling Fellowships. Awards available are : Medicine, 2 ; Natural Sciences, 2 ; Humanities, 1 ; Social Sciences, 1.

Library.—The following donations were received : parts of periodicals, 131 ; purchased parts, 16.

The evening was devoted to a discussion on the Teaching of Science in Secondary Schools, and the speakers were : Professor P. D. F. Murray, Challis Professor of Zoology at the University of Sydney : " Biology in Secondary Schools." Mr. R. W. Stanhope, Lecturer in Chemistry, Sydney Teachers' College : " Some Recent Trends in Science Teaching." Dr. L. Short, Senior Lecturer, School of Applied Chemistry, N.S.W. University of Technology : " Teachers of Science and the Science They Teach."

September 7th, 1955. ·

The seven hundred and fifteenth General Monthly Meeting was held in the Hall of Science House, Sydney, at 7.45 p.m.

The President, Dr. M. R. Lemberg, F.R.S., was in the chair. Fifty-one members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificates of four candidates were read for the second time and the following persons were elected members of the Society : Patrick Joseph Coleman, Harry Sheffield Hancock, Alan Russel Heath, Raymond Farly Thew.

The following announcements were made : (1) The President, accompanied by the Hon. Secretary, waited on His Excellency the Governor of New South Wales, a Patron of the Society, and gave a report on the activities of the Society during the past year. (2) Members were informed that copies of the symposium on " Oil, Australia and the Future " are available to members and non-members at 5/– per copy. (3) The Pollock Memorial Lecture to be delivered by Dr. R. v. d. R. Woolley, F.R.S., on Thursday, October 20th, 1955, in the Physics Department, University of Sydney, would be entitled " Astronomy and Philosophy ". (4) French Technical Co-operation Scholarships—two scholarships for study in France for graduates in Engineering, Metallurgy or Science were available. Further particulars could be obtained from the office of the Society. (5) Archibald D. Olle Prize : As a result of the bequest of the late Mrs. A. K. Olle a prize known as the " Archibald D. Olle Prize " would be awarded " from time to time at the discretion of the Council to the member of the Society who in any year (in its opinion) submits to the Society the best treatise or writing or paper on any subject coming within the province of the Society for that year ". Council had decided that the first award of this prize be given for the best original research paper published in Volume 89, 1955, of the *Journal and Proceedings* of this Society, and that the value of the first award be £30.

The following resignations from membership of the Society were announced : E. C. Gyarfas and G. F. Joklik.

The following names have been erased from the List of Members and their indebtedness to the Society " written off " : John Rector and Bruce Ritchie.

Library.—The following donations were received : parts of periodicals, 173 ; purchased parts, 27.

The evening was devoted to a symposium on " Conservation of Water in Arid Regions ", and the following addresses were given : Professor Griffith Taylor, Emeritus Professor of Geography, University of Toronto : " Character and Extent of Arid Australia." Professor J. Macdonald Holmes, McCaughey Professor of Geography, University of Sydney : " Water Prospects in Remote Regions of Australia." Mr. W. H. Williamson, of the Water Conservation and Irrigation Commission, N.S.W. : " The Role of Groundwater in Western Districts of New South Wales." Mr. W. W. Mansfield, of the Division of Industrial Chemistry, C.S.I.R.O. : " Towards Reducing Evaporative Losses from Stored Water."

<center>October 5th, 1955.</center>

The seven hundred and sixteenth General Monthly Meeting was held in the Hall of Science House, Sydney, at 7.45 p.m.

The President, Dr. M. R. Lemberg, was in the chair. Twenty-four members were present. The minutes of the previous meeting were read and confirmed.

The Chairman announced the following deaths : James Douglas Stewart (September 17th) and George Davenport Osborne (October 5th).

The following announcements were made : (1) Archibald D. Olle Prize. The first award will be given for the best original research paper published in Volume 89, 1955, of the " Journal and Proceedings ". The value of the first award will be £30. (2) Pollock Memorial Lecture, entitled " Astronomy and Philosophy ", will be delivered by Dr. R. v. d. R. Woolley, F.R.S., on October 20th, in the Physics Department, University of Sydney.

The following resignations from membership of the Society were announced : Basil H. Flinter and Lennard R. Hall.

The following names have been erased from the List of Members and their indebtedness to the Society " written off " : Joan M. Charlwood and Albert V. Weatherhead.

Library.—The following donations were received : parts of periodicals, 96 ; purchased parts, 4.

Notice of Motion was made by the Council proposing alterations to the Rules of the Society.

The following papers were read by title only :

" The Palæozoic Rocks of the Wiseman's Creek-Burraga Area, N.S.W.", by R. L. Stanton.

" Studies of the Diastereoisomeric Effect. Part I. The Solubilities of (+) and (—) Tris-1 : 10-phenanthroline Ruthenium II Perchlorates in Solutions Containing Optically Active Ions ", by F. P. Dwyer, D.Sc., E. C. Gyarfas, M.Sc., Ph.D., and M. F. O'Dwyer, B.Sc.

" Studies of the Diastereoisomeric Effect. Part II. The Redox Potentials of the Systems (+) and (—) Tris-2 : 2'-Dipyridyl Osmium II (+) and (—) Tris-2 : 2'-Dipyridyl Osmium III in the Presence of Optically Active Electrolytes ", by G. T. Barnes, B.Sc., J. R. Backhouse, M.Sc., F. P. Dwyer, D.Sc., and E. C. Gyarfas, M.Sc., Ph.D.

The evening was devoted to the Commemoration of Great Scientists and the following addresses were given :

" Carl Friedrich Gauss ", by Professor G. Bosson, School of Mathematics, N.S.W. University of Technology.

" Georgius Agricola, Sixteenth Century Geologist, Mining and Metallurgical Expert ", by Mr. H. A. J. Donegan, of the N.S.W. Department of Mines.

" Some Medical Centenaries—1555, 1755, 1855 ", by Professor Harvey Sutton.

November 2nd, 1955.

The seven hundred and seventeenth General Monthly Meeting was held in the Hall of Science House, Sydney, at 7.30 p.m.

The President, Dr. M. R. Lemberg, F.R.S., was in the chair. Forty-seven members were present. The minutes of the previous meeting were taken as read.

The following announcement was made : The quarterly parts of the " Journal and Proceedings " are available, as issued, to those members requiring them in place of the bound volume which appears approximately three/four months after Part IV of any volume.

The following resignation of membership of the Society was announced : William L. Hayes.

Library.—The following donations were received : parts of periodicals, 59 ; purchased parts, 13 ; back numbers, 11.

Motion made by the Council regarding alterations to the Rules of the Society was carried.

1. Delete Rule VIII and replace by :

MEMBERS.

VIII. (*a*) There shall be the following categories of membership :

1. Ordinary Members.
2. Life Members.
3. Honorary Members.
4. Absentee Members.

Every candidate for admission as an ordinary or absentee member of the Society shall be recommended according to a prescribed form of certificate by not less than three members, to two of whom the candidate must be personally known.

The certificate shall be delivered to the Honorary Secretary and shall be considered at the Council Meeting next ensuing after its receipt. The names of the candidate and proposers shall be circulated to all members before each of the two following Ordinary General Meetings of the Society. The certificate shall be read at those meetings.

It shall be competent for a nominator to withdraw his/her support of a candidate at any time up to the second reading of the certificate by notice given in writing to the Honorary Secretary of the Society. Such withdrawal shall render the certificate informal.

The vote for admission shall take place by a show of hands, at the Ordinary General Meeting at which the certificate is appointed to be read for the second time ; unless not later than the Wednesday preceding this meeting the Council shall direct, or a member of the Society make written request to the Honorary Secretary for, a secret ballot. No election for a new member shall be valid unless twenty members at least record their votes.

At the election the assent of at least four-fifths of the members voting shall be requisite for the admission of the candidate.

ASSOCIATES.

VIII. (*b*) Council, on the nomination on a prescribed form of certificate of one member of the Society, may admit as an associate :

1. A spouse of a member.
2. An undergraduate attending a course for his/her first degree at a university or technical college.
3. Any other person under twenty-one (21) years of age.

An associate shall not be a member. An associate shall have the privileges of a member except that he/she may not vote, sign the Obligation Book, receive the " Journal and Proceedings ", or hold executive office.

2. Delete Rules IX, X, and replace by :

SUBSCRIPTIONS.

IX. The annual subscription, payable in advance, shall be as follows :

        Ordinary Membership   £3/3/–
        Absentee Membership   £2/2/–
        Associate   10/6

    The amount of thirty-five guineas may be paid at any one time by a financial member as a life composition for the ordinary annual payment.

    A member who has paid the annual subscription for thirty-five years shall become a life member without payment of further subscriptions.

    An absentee member is a member who is resident outside New South Wales.

    Ordinary members who are absent from the State may be granted absentee membership on application to the Council.

    The Council shall have the power to waive the annual subscription temporarily, for a period not exceeding two years, of any member who may in writing make such application to it on the grounds of financial difficulties.

X. The first annual subscription shall accompany the prescribed form of admission submitted by candidates for membership, and the nominations of associates.

3. Delete Rule XII and replace by :

NEW MEMBERS AND ASSOCIATES TO BE INFORMED OF THEIR ADMISSION.

XII. (*a*) Every new member shall receive due notification of his/her election, and be supplied with a copy of the Rules of the Society, a list of members, and a card of the dates of meetings. He/she shall also be requested to sign the Obligation Book or be supplied with a copy of the Obligation for his/her signature.

XII. (*b*) Every new associate shall receive due notification of his/her admission, and be supplied with a copy of the Rules of the Society, a list of members, and a card of the dates of meetings.

4.   SUBSCRIPTIONS IN ARREARS.

  XVII. Delete " members ", replace by " members or associates ", para. 1.

       Delete " member ", replace by " member or associate ", para. 2.

  XVIII. Delete " member ", replace by " member or associate ", para. 1.

       Delete " member ", replace by " member or associate ", para. 3.

5.   RESIGNATION OF MEMBERS OR ASSOCIATES.

  XIX. Delete " member ", replace by " member or associate ".

       Delete " membership ", replace by " membership or associateship ".

6. Delete Rule XX and replace by :

EXPULSION OF MEMBERS OR ASSOCIATES.

XX. (*a*) Four-fifths of the members present at any Ordinary General Meeting shall have power to expel any member from the Society, provided that a resolution to that effect has been moved and seconded at the previous Ordinary General Meeting, and that due notice of the same has been sent in writing to the member in question, within a week after the meeting at which such resolution has been brought forward. For this purpose, a quorum shall consist of thirty members. In the absence of a quorum, the resolution shall lapse.

XX. (*b*) Council shall have the authority to terminate an associateship for any cause whatsoever without being called upon to give its reasons.

7. XXXI (No. 7). Delete " by members of the Society ", replace by " according to the Library Rules ".

8.   COMMUNICATIONS TO THE SOCIETY.

  XXXII. Delete " members ", replace by " members or associates ".

9. Delete Rule XLII and replace by :

MEMBERSHIP OF SECTIONS.

XLII. Only members and associates of the Society shall have the privilege of joining any of the Sections.

The chairman of any Section must be a member of the Society.

10. ### LIBRARY.

XLVIII. Delete " members ", replace by " members or associates ".

11. In all instances where " his " is used, replace by " his/her ".

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The evening was devoted to a symposium on " Biology of Arid Regions ", and the following addresses were given :

" Plants and Soil of Semi-Arid Australia ", by Professor N. C. W. Beadle, of the Botany Department, The University of New England, Armidale, N.S.W.

" The Insects of Arid Regions, as illustrated by the Grasshoppers ", by Dr. K. H. L. Key, Principal Research Officer, C.S.I.R.O. Division of Entomology, Canberra.

" Vertebrates and the Desert ", by Dr. J. A. Keast, of the Australian Museum, Sydney.

The following film was shown by courtesy of the N.S.W. Film Council :

" Desert Glory."

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December 7th, 1955.

The seven hundred and eighteenth General Monthly Meeting was held in the Hall of Science House, Sydney, at 7.45 p.m.

Dr. Ida A. Browne, Vice-President, was in the chair. Thirty-one members and visitors were present. The minutes of the previous meeting were read and confirmed.

The following resignation from membership of the Society was announced : Albert J. Mahoney. It was also announced that the name of John J. Veevers had incorrectly been included in the list of names of members who had resigned from membership of the Society during July, 1955.

The following name has been erased from the list of members and his indebtedness to the Society " written off " : William H. Watkins.

Library.—The following donations were received : parts of periodicals, 64 ; purchased parts, 17 ; back numbers, 9.

The evening was devoted to the presentation of the following papers :

" The Normal Vibration Frequencies of XY_3Z_3 Molecules Belonging to the Point Group D_{3h} ", by A. Keane. (Read by title only.)

" The Volcanic Stratigraphy of the Minyon Falls District, N.S.W.", by K. A. W. Crook and J. W. McGarity. (Read by title only.)

" The Essential Oil of *Backhousia myrtifolia* Hooker *et* Harvey. Part III. Single-tree Studies on the Physiological Forms from Queensland ", by R. O. Hellyer, H. H. G. McKern and J. L. Willis. (Previously read by title only.)

" Ilmenite from Beach Sands of New South Wales ", by C. E. Curnow and L. G. Parry. (Communicated by Professor R. S. Nyholm and previously read by title only.)

" Determination of Flow-Index in a Mine ", by C. M. Groden, M.Sc. (Communicated by Mr. A. Keane.)

" *Bœckea citriodora :* A New Member of the Myrtaceæ ", by A. R. Penfold and J. L. Willis.

" *Melaleuca viridiflora* Gaertn. and its Essential Oils ", by R. O. Hellyer and H. H. G. McKern.

" Regional Magnetic Survey of the South Sydney Basin ", by V. Bhaskara Rao, M.Sc., and H. Narain, Ph.D. (Communicated by Dr. J. A. Dulhunty.)

" Leucoxenic Grains in Dune Sands at North Stradbroke Island, Queensland ", by H. G. Golding, A.R.C.S., B.Sc.

" On Weber Transforms ", by J. L. Griffith, B.A., M.Sc.

JOURNAL AND PROCEEDINGS

OF THE

ROYAL SOCIETY

OF NEW SOUTH WALES

Royal Society of New South Wales

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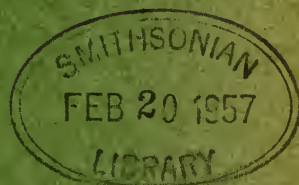# V O L U M E   9 0

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JOURNAL AND PROCEEDINGS

OF THE

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Edited by the Honorary Editorial Secretary

JOURNAL AND PROCEEDINGS

OF THE

ROYAL SOCIETY

OF NEW SOUTH WALES

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PART
I

1956

A

Royal Society of New South Wales

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REPORT OF THE COUNCIL FOR THE YEAR ENDING 31st MARCH, 1956.

PRESENTED AT THE ANNUAL AND GENERAL MONTHLY MEETING OF THE SOCIETY, 4TH APRIL, 1956, IN ACCORDANCE WITH RULE XXVI.

The membership of the Society at the end of the period under review stood at 341, a decrease of 13 on the membership of the previous year. Seventeen new members were elected during the year, and the following members were lost by resignation : George G. Blake, John H. Caldwell, Harold B. Carter, Roslyn A. Crane, Clem N. Davison, Basil H. Flinter, Alex. J. Gibson, Eleonora C. Gyarfas, Lennard R. Hall, William L. Hayes, Harold T. Howard, William Johnson, Gunther F. Joklik, Gladys O. Lowenbein, Hugh A. McKenzie, Albert J. Mahoney, Harry N. S. Schafer, Ruth Winchester and John O. Zehnder.

The following names were erased from the list of members : Joan M. Charlwood, John Rector, Bruce Ritchie, William H. Watkins and Albert V. Weatherhead.

Six members have been lost to the Society by death since 1st April, 1955 :

Frank Stanley Cotton (elected 1919).
Martin Raphael Freney (elected 1940).
Henry Maxwell Harris (elected 1949).
Edward Eugene Hirst (elected 1936).
George Davenport Osborne (elected 1921).
James Douglas Stewart (elected 1900).

There were nine General Monthly Meetings held, the average attendance being 44. These include the Annual Meeting, three symposia, two commemorations and one discussion. One evening was devoted to the reading of papers and another to the screening of scientific films.

The symposia were :

1st June : " New Guinea."
" New Guinea and Its Peoples ", by Professor A. P. Elkin.
" Dental and General Health in New Guinea-Papua ", by Dr. N. E. Goldsworthy.
" Some Aspects of Agricultural Development—Papua and New Guinea ", by Mr. W. Cotrell-Dormer.
" Some Factors in New Guinea's History ", by Mr. J. A. Miles.

7th September : " Conservation of Water in Arid Regions."
" Character and Extent of Arid Australia ", by Professor G. Taylor.
" The Role of Groundwater in Western Districts of New South Wales ", by Mr. W. H. Williamson.
" Towards Reducing Evaporative Losses from Stored Water ", by Mr. W. W. Mansfield.
" Water Prospects in Remote Regions of Australia ", by Professor J. Macdonald Holmes.

2nd November : " Biology of Arid Regions."
" Plants and Soils of Semi-Arid Australia ", by Professor N. C. W. Beadle.
" The Insects of Arid Regions, as Illustrated by the Grasshoppers ", by Dr. K. H. L. Key.
" Vertebrates and the Desert ", by Dr. J. A. Keast.
By courtesy of the N.S.W. Film Council, the film " Desert Glory " was shown.

Commemorations.

6th July : At the Commemoration of the late Albert Einstein members were addressed by Dr. Ilse Rosenthal-Schneider and Professor V. A. Bailey.

5th October : At the Commemoration of Great Scientists, the following addresses were given :

" Carl Friedrich Gauss ", by Professor G. Bosson.
" Georgius Agricola, Sixteenth Century Geologist, Mining and Metallurgical Expert ", by Mr. H. A. J. Donegan.
" Some Medical Centenaries—1555, 1755, 1855 ", by Dr. Harvey Sutton.

Discussion.

3rd August : '' The Teaching of Science in Secondary Schools.''
'' Biology in Secondary Schools '', by Professor P. D. F. Murray.
'' Some Recent Trends in Science Teaching '', by Mr. R. W. Stanhope.
'' Teachers of Science and the Science they Teach '', by Dr. L. Short.

Films.

4th May :
'' Power of the Highlands '', shown by courtesy of the N.S.W. Film Council.
'' Packaged Power '', shown by courtesy of Australian Aluminium Co. Pty. Ltd., and
a representative of this Company attended the meeting to discuss this film.
'' Wealth from Water '', shown by courtesy of the Snowy Mountains Hydro-Electric
Authority.

Papers.—Twenty-four papers were accepted for reading and publication by the Society,
an increase of seven papers from the previous year.

Alterations to the Rules.—At the General Monthly Meeting held 2nd November, a motion
regarding alterations to the Rules was adopted. This motion was confirmed at the meeting held
7th December. A full text of the alterations to the Rules was contained in the Abstract of
Proceedings of the meeting held 2nd November, 1955 (Vol. LXXXIX).

These alterations to the Rules allow the admission to the Society of undergraduates and
wives of members as associates.

Annual Social Function.— Sherry Party was held on 21st March and was attended by 49
members and friends.

The Section of Geology had as Chairman Dr. J. A. Dulhunty, and Mr. L. J. Lawrence was
Hon. Secretary of the Section. Five meetings were held during the year, the average attendance
being 18 members and visitors. The meetings included notes and exhibits, addresses and one
symposium.

The meetings of the Section of Geology are now held bi-monthly and alternatively with
bi-monthly meetings of the Geological Society of Australia, and each Society gives notice of the
other Society's meetings on its notice paper for general monthly meetings. This was approved
by Council at its meeting held 25th May.

The Council of the Society held ten ordinary meetings. The attendance of members of
Council was as follows : Dr. Lemberg 9, Dr. Bosworth 9, Dr. Ida Browne 10, Mr. McCarthy 8,
Dr. Magee 9, Mr. Griffith 10, Mr. Hanlon 9, Mr. Donegan 7 (on leave for one meeting), Rev.
Burke-Gaffney 10, Professor Craig 3, Dr. Dwyer 5, Mr. Fletcher 6, Dr. Gibson 6, Mr. Harper 8,
Professor McMahon 3 (on leave for 4 meetings), Dr. Osborne 4, Mr. Proud 5, Professor Taylor 6,
Dr. Dulhunty 3.

Appointment of Councillor.—At the meeting of Council held 26th October, Dr. Dulhunty
was appointed a member of Council to fill the vacancy caused by the death of Dr. G. D. Osborne.
At this meeting Council expressed its appreciation of the work of Dr. Osborne in the following
terms : '' That this Council expresses its sense of loss in the death of Dr. G. D. Osborne on 5th
October, 1955, and desires to place on record its appreciation of his services to the Society. Dr.
Osborne first joined the Council in 1941, and was a member at the time of his death. He was
President, 1944–45 ; Hon. Treasurer, 1946–47, 1947–48 ; Hon. Editorial Secretary during 1953 ;
and served on many committees, including Science House Management Committee.

On Science House Management Committee the Society was represented by Mr. H. A. J.
Donegan and Dr. R. C. L. Bosworth ; substitute representatives were Mr. F. R. Morrison and
Mr. J. S. Proud.

Commemoration of the Landing of Captain James Cook.—This commemoration was cancelled
owing to the inclement weather.

At the meeting of the Board of Visitors of the Sydney Observatory held on 8th March,
the Society was represented by Dr. M. R. Lemberg, F.R.S.

The President, accompanied by the Hon. Secretary, waited on His Excellency the Governor
of New South Wales on 7th July. A report was given to His Excellency on the activities of the
Society during the past year.

At the meeting of A.N.Z.A.A.S. held at Melbourne, 17th–24th August, 1955, the Society's
delegates were Dr. Ida A. Browne and Dr. M. R. Lemberg, F.R.S.

Professor R. S. Nyholm, the immediate past President, was awarded the H. G. Smith
Memorial Medal for 1955. The award is for the best contributions over the past ten years to the
development of chemical science in the fields of physical and inorganic chemistry.

Nuffield Foundation Dominion Travelling Fellowships have been awarded to Dr. John
Cymerman-Craig and Mr. William Hutton Lockwood, both Fellowships in the Natural Sciences.

Olle Award.—Under a bequest of the late Mrs. Olle, a prize, known as the '' Archibald D.
Olle Prize '', will be awarded from time to time at the discretion of the Council to the member of

the Society who in any year (in its opinion) submits to the Society the best treatise, or writing, or paper, on any subject coming within the province of the Society for that year ". The first award will be given for the best original research paper published in Volume LXXXIX, 1955, of the *Journal and Proceedings*. The value of the first award will be £30.

The Clarke Medal for 1956 was awarded to Professor O. W. Tiegs, D.Sc., F.R.S., for distinguished contributions in the field of zoology, particularly those on the embryology of insect groups.

The Society's Medal for 1955 was awarded to Dr. W. G. Woolnough in recognition of his pioneering geological work in Australia and the Pacific Islands and for outstanding contributions to geological thought.

The James Cook Medal for 1955 was awarded to Professor A. P. Elkin for his distinguished contributions in the field of anthropology.

The Edgeworth David Medal for 1955 was awarded to Dr. H. B. S. Womersley for his distinguished contributions in the field of botany.

The Clarke Memorial Lecture for 1955 was delivered by Mr. R. O. Chalmers on 16th June. The title of the lecture was " Some Aspects of New South Wales Gemstones ".

During the year a new typewriter was purchased for the office at a cost of £101 10s. The one previously used in the office was transferred to the library.

The financial position of the Society, as disclosed by the audit, is a satisfactory one, showing a surplus of income over expenditure of £745 6s. 8d., converting last year's deficit of £331 4s. to a credit balance of £404 15s. 9d. in the Commonwealth Savings Bank Account and a small overdraft of £85 6s. 7d. in our Cheque Account. This surplus is largely due to sales of periodicals and books no longer required in our library amounting to £1,628 15s. 10d.

The Society's share of the profits from Science House during the year was £879 11s. 2d. The rentals to be charged owner-bodies of Science House have now been determined. It has been agreed that all owner-bodies of Science House should pay the rent which operated before the Fair Rents Court's determination plus 60%, and the Society's income from Science House for this year includes a refund of rent overpaid during the previous financial year.

The Society has again received a grant from the Government of New South Wales, the amount being £500. The Government's continued interest in the work of the Society is much appreciated.

The Library.—The Library Committee met once during the year ended 29th February. The committee consisted of Dr. Lemberg, Dr. Bosworth, Mr. Griffith, Mr. Hanlon, Dr. Rountree, Dr. Magee, Dr. Dwyer and Mr. Wood. The assistant librarian, Mrs. B. Sommerville, attended by invitation. The meeting was held on 22nd September.

It is with regret that we have to announce the resignation of Mrs. Sommerville, whose appointment terminated on 18th November. We should like to record our appreciation of the valuable services to the library made by Mrs. Sommerville. She has been succeeded by Mrs. Enid Wilson, M.A.

The amount of £158 15s. 8d. was expended on the purchase of periodicals.

The amount of £72 has been spent on binding journals in the library. A further amount of £80 was approved by Council at its meeting held 26th October for binding. This is to cover work in hand at present at the book-binder's.

Exchange of publications is maintained with 408 societies and institutions.

For the twelve months ended 29th February the number of accessions added to the library was 2,355.

The number of books and periodicals borrowed by members and accredited readers was 344.

Disposal by sale of periodicals from the library amounted to £1,628 15s. 10d.

Revision of the library catalogue continues, new and amended entries being forwarded to Pitt's catalogue.

Among the institutions which made use of the library through the inter-library scheme were C.S.I.R.O. Coal Research Station ; Head Office, Melbourne ; McMaster Animal Health Laboratory ; Division of Fisheries ; Division of Industrial Chemistry ; Wool Textile Research Laboratories ; Division of Entomology ; Division of Plant Industry ; Division of Food Preservation ; National Standards Laboratory ; C.S.I.R.O. Library, Canberra ; Fisher Library, University of Sydney ; Geology Department, University of Sydney ; Engineering Department, University of Sydney ; Australian National University ; University of Melbourne ; University of Western Australia ; University of New England ; N.S.W. University of Technology ; University of Tasmania ; Sydney Technical College ; Wollongong Technical College ; Melbourne Public Library ; Forestry Commission of N.S.W., Wood Technology Division ; Dental Hospital, Sydney ; Bureau of Mineral Resources, Canberra ; Queensland Institute of Medical Research ; N.S.W. Department of Health ; Animal Health Station, Brisbane ; Royal North Shore Hospital ; Snowy Mountains Hydro-Electric Authority ; Sydney County Council ; Herbarium Library ; Colonial Sugar Refining Co. Ltd., Sydney ; Sugar Research Institute, Queensland ; Johnson & Johnson, Ltd. ; B.A.L.M.

M. R. LEMBERG, F.R.S.,
President.

THE ROYAL SOCIETY OF NEW SOUTH WALES.

BALANCE SHEET AS AT 29th FEBRUARY, 1956.

LIABILITIES.

1955. £		1956. £ s. d.	£ s. d.
383	Australian and New Zealand Bank Ltd.—Overdraft		85 6 7
39	Subscriptions Paid in Advance		17 17 0
115	Life Members' Subscriptions—Amount carried forward		142 19 0
	Trust and Monograph Capital Funds (detailed below)—		
	Clarke Memorial	1,891 19 0	
	Walter Burfitt Prize	1,121 18 5	
	Liversidge Bequest	738 17 9	
	Monograph Capital Fund	3,852 14 7	
	Olle Bequest	35 4 7	
7,617			7,640 14 4
22,913	ACCUMULATED FUNDS		23,652 17 6
	Contingent Liability (in connection with Perpetual Lease.)		
£31,067			£31,539 14 5

ASSETS.

1955. £		1956. £ s. d.	£ s. d.
6	Cash at Savings Bank and in Hand		406 10 9
	Investments—		
	Commonwealth Bonds and Inscribed Stock— at Face Value— Held for—		
	Clarke Memorial Fund	1,800 0 0	
	Walter Burfitt Prize Fund	1,000 0 0	
	Liversidge Bequest	700 0 0	
	Monograph Capital Fund	3,000 0 0	
	General Purposes	2,460 0 0	
8,960			8,960 0 0
	Debtors for Subscriptions	77 3 6	
	Less Reserve for Bad Debts	77 3 6	
14,835	Science House—One-third Capital Cost		14,835 4 4
6,800	Library—At Valuation		6,800 0 0
443	Furniture and Office Equipment—At Cost, less Depreciation		516 19 4
21	Pictures—At Cost, *less* Depreciation		20 0 0
2	Lantern—At Cost, *less* Depreciation		1 0 0
£31,067			£31,539 14 5

TRUST AND MONOGRAPH CAPITAL FUNDS.

	Clarke Memorial.			Walter Burfitt Prize.			Liversidge Bequest.			Monograph Capital Fund.			Olle Bequest.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Capital at 29th February, 1956	1,800	0	0	1,000	0	0	700	0	0	3,000	0	0	—		
Revenue—															
Balance at 28th February, 1955 ..	69	18	0	89	8	9	16	3	1	941	8	9	—		
Income for twelve months	58	9	6	32	9	8	22	14	8	116	18	11	35	4	7
	128	7	6	121	18	5	38	17	9	1,058	7	8	35	4	7
Less Expenditure ..	36	8	6	—			—			205	13	1	—		
Balance at 29th February, 1956	£91	19	0	£121	18	5	£38	17	9	£852	14	7	£35	4	7

ACCUMULATED FUNDS.

	£	s.	d.
Balance at 28th February, 1955	22,913	10	4
Add—			
Decrease in Reserve for Bad Debts	38	2	6
Surplus for twelve months (as shown by Income and Expenditure Account)	745	6	8
	23,696	19	6
Less Bad Debts Written Off	44	2	0
Balance at 29th February, 1956	£23,652	17	6

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of the Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on the 29th February, 1956, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

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HORLEY & HORLEY,
Per Conrad F. Horley, F.C.A. (Aust.),
Chartered Accountants (Aust.).

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Prudential Building,
39 Martin Place, Sydney.
15th March, 1956.

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(Sgd.) H. A. J. DONEGAN,
Honorary Treasurer.

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INCOME AND EXPENDITURE ACCOUNT.

1st MARCH, 1955, to 29th FEBRUARY, 1956.

1955. £		1956. £ s. d.	£ s. d.
	To Annual Social Function—		
	Expenditure £62 16 8		
	Less Received 40 0 0		
5		22 16 8	
31	,, Audit..	31 10 0	
87	,, Cleaning	104 0 0	
26	,, Depreciation	29 4 2	
44	,, Electricity	43 17 9	
2	,, Entertainment Expenses	1 10 8	
24	,, Insurance	35 19 1	
218	,, Library Purchases and Binding	239 19 1	
142	,, Miscellaneous	167 9 9	
134	,, Postages and Telegrams	135 14 7	
	,, Printing and Binding Journal—		
	Vol. 87, Binding £120 0 0		
	Vol. 88, Parts 1–4 .. .. .. 673 11 9		
	Vol. 89, Part 1 .. .. .. 414 18 9		
476		1,208 10 6	
127	,, Printing—General	168 8 4	
51	,, Rent—Science House Management	30 19 8	
60	,, Repairs	5 14 4	
1,046	,, Salaries	1,101 1 2	
11	,, Symposium	—	
29	,, Telephone	30 14 9	
			3,357 10 6
—	,, Surplus for twelve months .. .. :. ..	745 6 8	
£2,503			£4,102 17 2

1955. £		1956. £ s. d.
875	By Membership Subscriptions	882 0 0
9	,, Proportion of Life Members' Subscriptions	8 8 0
450	,, Government Subsidy	500 0 0
411	,, Science House Management—Share of Surplus	879 11 2
83	,, Interest on General Investments	79 18 6
222	,, Reprints	124 3 8
122	,, Other Receipts—Sale of Periodicals *ex* Library	1,628 15 10
331	,, Deficit for Twelve Months	—
£2,503		£4,102 17 2

ABSTRACT OF THE PROCEEDINGS

OF THE SECTION OF

GEOLOGY

Chairman : J. A. Dulhunty, D.Sc.
Hon. Secretary : L. J. Lawrence, B.Sc., Dip.Com.

Meetings.—Five meetings were held during the year, with an average attendance of eighteen members and visitors. The reduced number of meetings, compared with previous years, was mutually agreed upon by the Royal Society of New South Wales and the newly formed Geological Society of Australia. Both Societies will now hold alternate monthly meetings throughout the year.

March 18th.—
  (a) Dr. W. R. Browne spoke of the need for further study of the Tertiary and Post-Tertiary Geology of the State.
  (b) Dr. G. D. Osborne showed slides of what he believed to be Pleistocene sediments near Long Bay.
  (c) Mr. L. J. Lawrence showed specimens of cassiterite from northern New England, believed to have been formed at relatively low temperature.
  (d) Dr. T. G. Vallance exhibited an original William Smith geological map.
  (e) Dr. L. E. Koch showed specimens of vivianite from the alluvials of the Cobargo District. Dr. Koch spoke of the occurrence and possible origin of the vivianite.
  (f) Mr. H. G. Golding showed specimens of discoidal barite found in the sandstone of the Gosford District.

April 15th.—Address by Dr. T. G. Vallance entitled " Illustrated Notes on an Overseas Journey ". Dr. Vallance spoke of the current research being conducted at a number of British and American Universities and showed slides of several of the overseas University buildings.

May 20th.—Address by Dr. R. T. Wade entitled " Fossil Fishes—Their Structure, Identification and Occurrence in N.S.W. ". Dr. Wade discussed the various criteria for the recognition of the several sub-classes. Dr. Wade traced the evolution of fishes and discussed their occurrence at Brookvale and Talbragar in N.S.W.

July 15th.—Symposium entitled " Contributions to the Study of Tertiary and Quaternary Sedimentation in Eastern Australia ". Dr. W. R. Browne outlined the present state of knowledge concerning post-Mesozoic stratigraphy and presented a stratigraphic table showing the various terrestrial and marine subdivisions.
    Dr. R. L. Crocker discussed means of dating the post-Mesozoic sediments. He outlined the difficulties involved due to the lack of ancient cultures and the limited success of pollen analysis.
    Mr. J. McGarity discussed the physiographic and climatological implications as evidenced by the sub-basaltic soils of the north coast of N.S.W.
    Mr. A. S. Ritchie considered the tectonic implication of the Pleistocene sand deposits of the **Tomago** District.

October 21st.—Address by Dr. J. A. Dulhunty entitled " Recent Developments in Coal and Coalfield Research in N.S.W.". Dr. Dulhunty outlined his researches in experimental rank variation under varying conditions of temperature and pressure. He discussed the physical condition of the resulting product and the relationship between laboratory synthesis of various coal ranks and the equivalent ranks formed under natural conditions of sedimentary burial with special reference to N.S.W. coalfields.
    The Section recorded its deep regret at the passing of Dr. G. D. Osborne.

Obituary

FRANK STANLEY COTTON. The death occurred on 23rd August, 1955, aged sixty-five years, of Frank Stanley Cotton. He is survived by his wife and two sons.

Professor Cotton, who was a member of the Society for forty-seven years, was born on 30th April, 1890. He was educated at Sydney High School and the University of Sydney, graduating B.Sc. in 1912. In 1913 he was appointed Lecturer in Physiology. The degree of D.Sc. was conferred on him in 1931. He was appointed Research Professor in 1940, and in 1946 became Professor of Physiology.

Professor Cotton published a series of papers dealing with the effect of athletic exercise on the heart and circulation, his doctorate thesis being an investigation of the quantity of blood mobilized by active muscles during exercise.

During the last war he invented the " anti-G " suit, which overcame the tendency for fighter pilots to black-out during violent air manœuvres and which was officially adopted by the R.A.A.F.

In his youth Professor Cotton was a champion swimmer, and devoted a great deal of his time, in later years, to helping present-day swimming champions.

In May, 1955, the University Senate granted him an Emeritus Professorship.

MARTIN RAPHAEL FRENEY was born in Western Australia in 1909. His early schooling was received in South Australia, where he attended St. Peter's College, and later Adelaide University He graduated B.Sc. in 1930, and worked in the Biochemistry Department of the University for a short period.

He carried out research on the blowfly problem, first as a Junior Research Student under the Science and Industry Endowment Fund, and later with the C.S.I.R.O., Division of Economic Entomology, Canberra, including two years as senior student at University College, London, under the late Professor J. C. Drummond.

In 1936 he was transferred to C.S.I.R.O. Division of Animal Nutrition, being stationed at the McMaster Laboratory, Sydney. His research at this stage was on fleece chemistry and the shrink-proofing of wool with alcoholic alkali, later transferring, temporarily, to the C.S.I.R.O., Division of Industrial Chemistry. In 1942 he was seconded to the Central Wool Committee.

After the war he returned to C.S.I.R.O., and in 1946 proceeded overseas, visiting England, the U.S.A. and South Africa. He was later appointed to the Wool Textile Research Laboratories of C.S.I.R.O. Ill health led to his early retirement in 1952. He died suddenly on 2nd April, 1955.

Although Freney was more inclined to administrative work, he was a meticulous experimental worker. Outwardly reserved, he possessed an underlying kindly and generous disposition. His tragic passing at such an early age is greatly regretted by those who were closely associated with him in his work.

GEORGE DAVENPORT OSBORNE. The sudden death of George Davenport Osborne on 5th October, 1955, at the fige of fifty-six, was a great shock to his colleagues and friends, although his health had not been good over the last few years.

After graduation he joined the Department of Geology at Sydney University as Demonstrator. He was appointed to a Lectureship in 1924 and subsequently promoted to a Readership in 1949. His geological interests were wide, but his main interest lay in petrology and tectonic geology. In 1929 he was awarded the degree of Doctor of Science as a result of his researches into the structural and stratigraphical geology of the Hunter River area. He also received the degree of Doctor of Philosophy for his researches in petrology at Cambridge.

He was a prominent member of local scientific societies. He was President of the Linnean Society of New South Wales in 1948 and served on its Council for many years. He was associated with committees of Section C of A.N.Z.A.A.S. for the Tectonic Map of Australia and for Glacial Phenomena.

Dr. Osborne gave much time to the service of the Royal Society of New South Wales. He was elected a member in 1921. He served for many years as a Member of Council, serving terms

as Honorary Treasurer and Honorary Editorial Secretary, and was President in 1944. He published twelve papers in the Society's Journal and many papers in other scientific publications. He was author of the Society's Monograph No. 1—" The Structural Evolution of the Hunter-Manning-Myall Province, New South Wales ".

He is survived by his wife and two sons.

JAMES DOUGLAS STEWART. On 17th September, 1955, at the age of eighty-six years, James Douglas Stewart, Emeritus Professor of Veterinary Science in the University of Sydney, died.

Professor Stewart was born at Windsor, N.S.W., in 1869, and was educated at Sydney Grammar School and, later, went to Edinburgh and studied veterinary science. He returned to Australia as a young graduate of the Royal Veterinary College, London. His early appointments included that of Lecturer at the Sydney Technical College, Chief Inspector of Stock, N.S.W., and Acting Director of Veterinary Services, Melbourne. In 1909 he was invited to fill the newly created Chair of Veterinary Science at the University of Sydney.

He was responsible for the development of an efficient veterinary service in New South Wales and initiated measures for the control of two of the great scourges of the cattle industry—tuberculosis and the cattle tick.

Professor Stewart was elected to membership of this Society in 1900, was a member of Council 1924–26, and President 1927–28. In 1934 he was President of the Veterinary Surgeons' Board, N.S.W.

His services to agriculture were recognized by his election as an Honorary Life Member of the Royal Agricultural Society of New South Wales, and, in 1936, was elected Honorary Fellow of the Royal College of Veterinary Surgeons, England and, as an Associate of that body, the highest honour in its gift, in 1949.

EDWARD EUGENE HIRST was born in 1884 and came to Australia as Managing Director of the British General Electric Co. Ltd. in 1912.

He was the founder of the Corps of Commissionaires in New South Wales and in Victoria, Patron of the Old Contemptibles' Association and of the Mons Veterans' Association.

Mr. Hirst was a great animal lover, known for his horses, dogs and birds and for having introduced the game of Polocrosse to Australia. His many and varied interests included books, pictures and antiques.

He retired when his health failed in 1952, and died on 24th October, 1955.

Mr. Hirst was elected to membership of the Society in 1936.

HENRY MAXWELL HARRIS died on 16th February, 1956. He was educated at Newington College and Sydney University, graduating B.Sc., B.E., 1944–48, and was elected to membership of the Society in 1949, at which time he was Assistant Engineer with the Water Conservation and Irrigation Commission, Farm and Water Division. He resigned from this position at the end of this same year.

A list of members of the Royal Society of New South Wales up to 1st April, 1955, is included in Volume LXXXIX.

During the year ended 31st March, 1956, the following have been elected to membership of the Society :

Campbell, Ian Gavin Stuart, b.sc., Schoolmaster, Wesley College, Prahran, Victoria.

Coleman, Patrick Joseph, Lecturer in Geology, The University of Sydney.

Colville, (Mrs.) Jean Norma, b.sc., Geological Section, Joint Coal Board ; p.r. 4 The Postern, Castlecrag.

Crawford, Edwin John, b.eng. (*Syd.*) ; p.r. " Lynwood ", Bungalow-avenue, Pymble.

Crawford, Ian Andrew, 73 Wyadra-avenue, North Manly.

Denton, Leslie A., Bunarba-road, Miranda.

Denton, (Mrs.) Norma F., Bunarba-road, Miranda.

Durie, Ethel Beatrix, b.sc., m.b., ch.m., f.r.a.c.p., Institute of Medical Research, Royal North Shore Hospital, St. Leonards.

Hancock, Harry Sheffield, b.sc., 491 New Canterbury-road, Dulwich Hill.

Heath, Russel Alan, Metallurgist, " Heathcot ", 9 Potter-avenue, Earlwood.

Keane, Austin, m.sc., Lecturer, School of Mathematics, N.S.W., University of Technology, Broadway.

Lang, Thomas Arthur, m.c.e., m.i.e. (*Aust.*), a.m.a.s.c.e., f.r.i.p.a., Associate Commissioner, Snowy Mountains Hydro-Electric Authority, Cooma, N.S.W.

Mandl, Lothar Max, Dipl.Ing. (*Technical University of Vienna*), a.s.t.c. (Hons.), a.m.i.e. (*Aust.*), Senior Technical Officer, C.S.I.R.O., Division of Electrotechnology ; p.r. 198 Queen-street, Woollahra.

Marsden, Joan Audrey, Laboratory Assistant, 203 West-street, Crows Nest.

Moss, Francis John, m.b., b.s. (*Melb.*), 15 Ormonde-road, Roseville Chase, N.S.W.

Thew, Raymond Farly, a.m.Mech.e.a., f.g.a.a., a.p.i.a., Engineer, 88 Braeside-street, Wahroonga.

Thorley, Geraldine Lesley, b.a., 1290 Pacific-highway, Turramurra.

The names of members who have died, resigned, or whose names have been removed from the list during the year are given in the Report of the Council.

AWARDS.

The Clarke Medal.

1955   Robertson, Rutherford Ness, b.sc. (*Syd.*), ph.d. (*Cantab.*), C.S.I.R.O. Plant Physiology Unit, Sydney.

The James Cook Medal.

1955   Elkin, Adolphus P., m.a., ph.d., Professor of Anthropology, University of Sydney, Sydney.

The Edgeworth David Medal.

1955   Womersley, Hugh B., m.sc., ph.d., Botany Department, University of Adelaide.

The Society's Medal.

1955   Woolnough, Walter George, d.sc., f.g.s., 28 Calbina-road, Northbridge.

PRESIDENTIAL ADDRESS

By M. R. LEMBERG, D.Phil., F.R.S.

With eight Text-figures.

PART I.

THE PAST YEAR AND SOME THOUGHTS ABOUT THE FUTURE.

You have heard a detailed report from the Council. You will not want me to repeat what has been reported in it. I shall therefore restrict myself to mentioning only a few administrative aspects and then deal with a few of the imponderables.

The reaching of an amicable settlement on the rents of the owner bodies of Science House was a matter of great satisfaction to me. Our finance is actually less sound than the balance sheet would suggest. We should not forget that the income of £1600 for sale of periodicals and books will not be repeatable and actually represents a loss of assets. We owe the success of this sale to a great deal of hard work by the Honorary Librarian, Dr. Bosworth, and the Assistant Librarian.

The Journal continues to cause us some concern. It suffers as all journals which publish papers in the whole field of science, even those of some very august bodies, from the preference of many contributors for a more specialised audience. There has been a greater number of contributions than in the year before, and papers from a wider field of the scientific disciplines have been accepted. This trend will, I hope, be strengthened by the Ollé award. It will have to continue if the Journal is to retain its exchange value, on which in turn much of our Library depends.

The costs of publication have risen again and this brings me back to the financial problem. We are sincerely thankful to the Government for its grant, and hope that it will see its way to increase it in order to maintain the services which this Society renders to Government departments by its Library and by its function in general to the community.

I wish to thank the members of the Council for their loyal support; the incoming Council will find that a satisfactory program for the coming year has been prepared. The Council has suffered a great loss in the death of Dr. G. D. Osborne.

Sincere thanks are due to the Executive, and above all to Dr. Ida A. Browne whose familiarity with the procedure of the Society alone has made it possible for me to step into the role of a President without the usual preparation of many years of service in the Council and Executive. Miss Ogle has run the office with the usual high efficiency. I also wish to thank many non-members who kindly helped us in various subcommittees or contributed papers to our Symposia.

We have thus reason to be moderately satisfied with the past year, if we compare its activities with those of previous years. If we, however, apply as measure the ideal function of the Society we have little reason for self-satisfaction.

The first aim of the Society, that of bringing together the scientists of the various disciplines, has become more difficult with increasing specialization, but all the more necessary.   The right balance between Symposia and the reading of papers has still to be found.   The former have certainly attracted larger audiences, but we must not neglect the reading of papers published in our Journal.   The art of presenting a short account of the main content of a specialized paper in such a way that its significance can be understood by scientists of other disciplines, is an art in which we all need practice.   We have altered the rules so that young scientists may enter the Society early and without financial embarrassment as Associates.   This can, however, only become effective if their teachers, particularly the Professors at Sydney University, show a greater active interest in the activities of the Society. I believe that this would not only greatly benefit the Society but also the University.

Another declared aim of the Society is to strengthen the contact between science and other fields of human endeavour, in art, literature, and philosophy. I feel that this aim has never been sufficiently implemented, although some of the symposia, e.g. that on " Teaching of Science in Secondary Schools " had a bearing on it.   We also contribute a little towards it by some of our Commemorations of great scientists, but it is discouraging that with the exception of the Einstein Commemoration, these were poorly attended.   Yet, the sound development of our civilization depends on this understanding between all the branches of human endeavour.   The educated layman who nowadays finds it almost impossible to understand specialized science, would perhaps be more attracted by discussions on such wider subjects than by popular lectures. The scientist, too, would benefit from a deeper knowledge of epistemology and the role which science has to play in the life of society.   Although many of our symposia have dealt well with such aspects from a practical and utilitarian point of view, the theoretical aspects should, I feel, not be wholly neglected. Personally I go even further than this.   The final task of a reintegration of our western thinking must be the reconciliation of science and religion, or the redefinition of their boundaries.   The time may be premature for this task, as Conant believes, but the aim should not be lost sight of.

Finally, the reorganization of science in Australia, begun by the formation of the Australian Academy of Science, will have to find a suitable place for the activities of the Royal Societies of the different states.   Again this is a problem which cannot be solved hastily, but this Society will, I am sure, do everything from its side to make it easier.

Part II.

CELLULAR RESPIRATION.

For the second part of my address I have chosen a subject which deserves the general interest of all scientists, since it deals with some of the most important chemical mechanisms in living cells.   Perhaps in no other field of the rapidly growing science of biochemistry has advance been more rapid and important.

Life is based upon the maintenance, by complicated and well-integrated chemical mechanisms, of a steady state, far from that of the equilibrium, and rich in chemical potential energy.   A crude analogy with hydroelectric schemes may be helpful.   Both the energies of living organisms and water-power are ultimately derived from the influx of radiating energy from the sun.   In the green plants light energy is converted to the chemical potential energy of starch and other organic substances in the process of photosynthesis, and other organisms receive parts of this energy in their food.   The same source provides

by evaporation and rain the potential energy of water in high places of the earth's crust. Water loses its gravitational energy by flowing down and the chemical potential energy of the organic substances is lost in their "combustion" by oxygen to carbon dioxide and water (or more correctly both are turned into energy and heat) in all but a few anærobic microorganisms. Man's ingenuity erects dams in the course of flowing water and converts its gravitational energy into more readily exchangeable electric energy which can be stored in batteries. Similarly Nature has her own most intricate systems of dams and sluices, the reaction steps, by which the respiratory energy is converted into the more readily exchangeable form of "high energy bonds", particularly the "energy rich" phosphate bonds of adenosine triphosphate (ATP), and its own storage batteries such as the compounds phosphocreatine (phosphagen) or phosphoarginine.

ENERGY OF CELLULAR RESPIRATION

ADP + P   ATP ⇌ PHOSPHAGEN

ENERGY REQUIRING PROCESSES
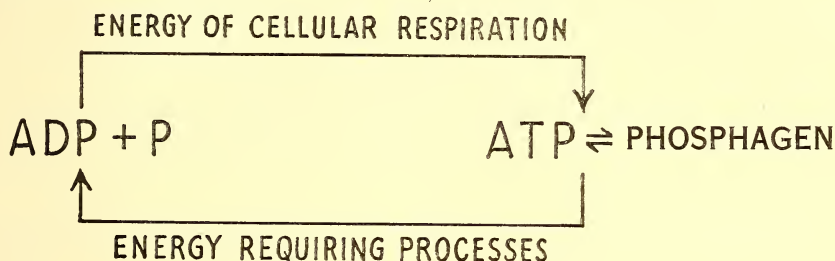
As electrical energy can ultimately be used for varied processes, so can this readily mobilisable form of high potential chemical energy serve the manifold energy-requiring processes in the organisms as well as yield muscular energy and heat.

Lipmann's concept of the energy-rich bond has proved itself as a veritable Ariadne thread through the labyrinth of the complicated intermediary reactions of cellular respiration. It must be admitted, however, that the localization of the potential energy in a single bond, i.e. that between oxygen (or nitrogen) and phosphorous, is an over-simplification. It has even caused confusion between chemists and biochemists. For the biochemist an "energy-rich" bond is a bond the *hydrolysis* of which *releases* a great deal of *free energy* ($-\Delta F°$), and which is therefore easily broken. For the chemist a bond of high energy is almost the opposite, a bond the *breaking* of which *requires* a great deal of heat energy ($+\Delta H°$), and which is therefore particularly firm. One may regret such differences of convention, but once they have been applied to large fields of knowledge they can no longer be altered and one has simply to understand them.

It is by such stepwise processes as those which will be described later, and in which "energy-rich" phosphate bonds are formed at the cost of respiratory energy that the steady state of the living organism is maintained. This can be expressed in the more exact but less simple language of thermo-dynamics, by stating that every living organism is an "open system" (Prigogine), in which a stream of negative entropy is attracted to compensate for the entropy increase which the living organism produces in its environment (Schroedinger in "What is Life?").

Historical development.

Our story can begin with van Helmont of Loewen University in Belgium (1577–1644). Not only do we owe him the word "gas" and the conception of a gas, and the recognition of the importance of chemical processes in life, but

he and his pupil Sylvius (1614–1672) were the founders of the phlogiston theory which was further developed by Becher (1635–1687) and Stahl (1660–1734). This theory postulated that a principle of combustibility (phlogiston) was present in combustible substances and lost from them in combustion. Combustion, respiration of animals and metal ash formation were recognized as related processes even before oxygen was discovered by Priestley (1733–1794) and Schele (1742–1786). That part of the air was absorbed by living animals as well as by burning candles was already known to Leonardo da Vinci (1452–1519). Sylvius wrote : Credendum est animalia ignemque particula ejusdem generis ex ære exhaurire. Ingenhous (1730–1799) observed the respiration of plants in the dark. Cavendish (1668–1735) discovered carbon dioxide (" dephlogist-onized carbon ") and hydrogen which he identified with phlogiston itself. The relation of respiration to heat evolution was already known to Mayow (1645–1679) who also first observed the change of colour of blood on oxygenation. It was still believed by Lavoisier (1743–1794) and even by Liebig (1840) and Julius R. Mayer that the respiration process was localized in the lung or in the blood. That it must occur in every single cell was first postulated by Moritz Traube in 1861 and by the plant physiologist Julius Sachs (1865) who clearly recognized the importance of cellular respiration for maintenance and growth of the protoplasm. (For these developments cf. Lieben's Geschichte der Physiologischen Chemie).

It is now generally believed that it was Lavoisier who liberated science from the shackles of the wrong phlogiston theory (see e.g. the exposition of Conant in " On Understanding Science "). Undoubted are the merits of Lavoisier of having first stressed the importance of weighing and of quantitative relationships in chemical reactions, and of having united—occasionally somewhat piratically—the knowledge of his time. But has he really shown the phlogiston theory to be wrong, or is not today's widely professed acceptance of Lavoisier's theory of oxidation as combination with oxygen another case which deserves Hilaire Belloc's caustic remark :

> " Oh ! let us never, never doubt
> What nobody is sure about " ?

In fact the phlogiston theory is nearer to the modern theory of oxidation as removal of electrons than is Lavoisier's theory. Suppose, e.g. that the oxidation of lactic to pyruvic, or of succinic to fumaric acid would have been known at Lavoisier's time better than the formation of metal oxides from metals, and one realizes how little Lavoisier's argument from the weight increase in the latter really mattered, and that Cavendish's identification of phlogiston with hydrogen is equally correct. The modern theory of oxidation (Fig. 1) is of course able

OXIDATION

$$Fe^{2+} - e \rightarrow Fe^{3+}$$
$$RH_2 - 2e \rightarrow R + 2H^+ \qquad RH_2 \rightarrow R + 2H$$
$$Mg - 2e \rightarrow Mg^{2+} \qquad Mg + \tfrac{1}{2}O_2 \rightarrow MgO$$
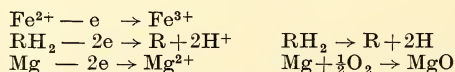
Fig. 1.—Oxidation.

to unite dehydrogenation, oxide formation and valency changes of metal ions all as removal of electrons. One can, indeed, trace lines of development from the phlogiston theory to the dehydrogenation theories of Hoppe-Seyler (1878) and Wieland (from 1912), and from Lavoisier to Liebig and to Warburg's Atmungsferment (1924). When Keilin (1925) based on earlier observations of MacMunn demonstrated the valency change ($Fe^{2+} \leftrightharpoons Fe^{3+}$) in the cytochromes, the time had arrived for a unification of the theory to which Leonor Michaelis contributed much.

For the present-day student of biochemistry it may be difficult to imagine the acerbity of the Warburg-Wieland discussion, in which Warburg postulated that only the activation of oxygen was required and that there could be no more than one Atmungsferment, and in which Wieland claimed that the dehydrogenases were only specific for the hydrogen donors, not for the hydrogen acceptors, and reacted with oxygen forming hydrogen peroxide, ultimately disposed of by the enzyme catalase. But I remember very well that as late as 1930, years after Keilin's work on the cytochromes, a " dualistic " theory was still unacceptable to many biochemists. Again, the cytochromes were only grudgingly admitted by Warburg, and so was the hæmatin nature of the Atmungsferment by Keilin.

These controversies are now a matter of the past, like the famous controversy between Pasteur and Liebig on whether fermentation was a biological or a catalytic phenomenon. When great men fight generally neither is quite wrong or quite right; the truth is not in the middle but above and beyond them.

ELECTRON (HYDROGEN) TRANSPORT
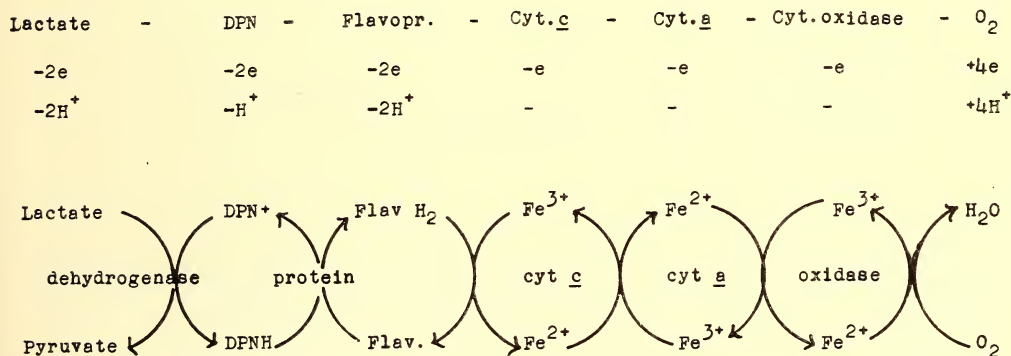
Fig. 2.—Electron (Hydrogen) Transport.

We should not forget these controversies, because they reveal the dangerous tendency of scientists to a *premature monism*. This leaning is a general human frailty, by no means restricted to scientists. It lies, I believe, at the root of the controversy between religion and science, with its serious consequences for our whole civilization.

It should not be overlooked, however, that during this time of conflict most significant advances were achieved. Barcroft and Warburg developed the technique of manometric measurement of tissue respiration; there is today hardly a biochemical laboratory without its Warburg apparatus. Thunberg developed this method of anærobic measurement of methylene blue discolouration as a useful tool in the study of dehydrogenases. While Wieland and others studied the dehydrogenases, further members of the respiratory chain, the pyridine nucleotides and flavoproteins were discovered by Warburg and Theorell and their chemical constitution explored by R. Kuhn, Karrer, v. Euler and Schlenk. Keilin refined the methods of microspectroscopy which enabled him to demonstrate the universal distribution of the cytochromes. He isolated cytochrome c and demonstrated the function of the Atmungsferment as cytochrome oxidase, thus laying the foundation for the working out of the respiratory chain. Warburg proved the hæmatin nature of the oxidase by studies on the inhibition of respiration by carbon monoxide and cyanide;

release of the carbon monoxide inhibition by light enabled him to measure its " photochemical absorption spectrum ". Thus came about the unravelling of the respiratory chain through which the electrons are transferred from the substrates to oxygen.

Electron transfer in the respiratory chain.

     As an example I use the relatively simple oxidation of lactic to pyruvic acid in animal tissues. The electron current (Fig. 2) flows from lactic acid activated by the enzyme lactic dehydrogenase first to diphosphopyridine nucleotide, from there to flavoprotein, then through several cytochromes and cytochrome oxidase to oxygen. The first two steps could be interpreted as dehydrogenations, e.g. $CH_3CHOHCO_2H - 2H \rightarrow CH_3COCO_2H$, but the interpretation as removal of two electrons and two protons, allows us to understand better the reduction of diphosphopyridine which involves two electrons but only one proton. Two electrons then flow on to flavoprotein,

$$\underset{|}{\overset{+}{N}} \diagup\!\!\!\!\diagup \overset{|}{C}H + 2e + H^+ \longrightarrow \quad \diagdown\!N\diagup \overset{|}{C}H_2$$

$$\diagdown\!N\diagup\!\!\!\!\diagup \overset{N\diagdown}{} + 2e + 2H^+ \longrightarrow \quad \diagdown\!N\diagup \overset{H\diagdown\!N\diagdown}{}$$
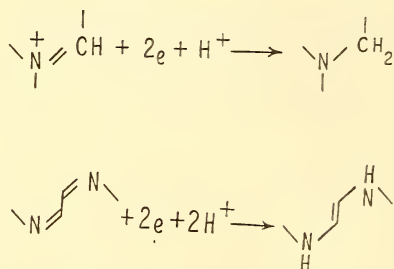
reducing its isoalloxazine ring. Since the oxidation of a flavoprotein involves two electrons, but the reduction of a cytochrome only one $(Fe^{3+}+e \rightleftharpoons Fe^{2+})$, two molecules of cytochrome must interact with one molecule of flavoprotein. Again, final reduction of oxygen to water requires the transfer of four electrons from four molecules of the ferrous oxidase : $O_2 + 4H^+ + 4e \rightarrow 2H_2O$.

     This poses a problem. The rapidity of the reactions excludes the assumption of triple collisions, e.g. in the reaction between a cytochrome and a flavoprotein. This reaction can thus only yield a radical with an unpaired electron. Michaelis has pointed out that such radicals resembling the semiquinones (Fig. 3) may be sufficiently stabilised by resonance to persist long enough to permit a second collision with another molecule of cytochrome to occur.

     Resonance in a molecule leads to a shift of light absorption from the ultraviolet into the visible or long wave ultraviolet part of the spectrum, and indeed, we find most of the respiratory catalysts to absorb in this region, i.e. to be coloured substances or near-coloured substances, if I may use this Iricism.

     Another important contribution of Michaelis was the demonstration of electron migration in complexes. In the cobalt-cysteine complex e.g. electrons migrate from cysteine (which becomes oxidised to cystine) to the central cobalt atom which becomes reduced to Co^{2+}, so that its reoxidation by oxygen can lead to futher oxidation of the cysteine bound to the cobalt. Such an electron conduction is necessary, e.g. in cytochrome *c* whose iron atom is not accessible to collisions. Such electron conduction is perhaps possible in even more complex adducts of proteins, and may have to be assumed to explain the electron transfer in the organised respiration chain of the mitochondria. Fig. 4 shows that the phosphopyridine nucleotides are not much more firmly bound than some of the substrates so that these " coenzymes " may shuttle between two different proteins (apoenzymes) as electron carriers. In the flavoproteins, however, the prosthetic group is more firmly bound, and in the hæmoproteins it is not

dissociable under physiological conditions. Sterical proximity of their prosthetic groups does not appear either to offer a satisfactory solution. While the possibility of electron conduction through the protein molecule is not yet established, it appears to me the most likely solution. In any case while four electrons are transferred to the oxygen by the oxidase, neither H_2O_2 nor HO_2
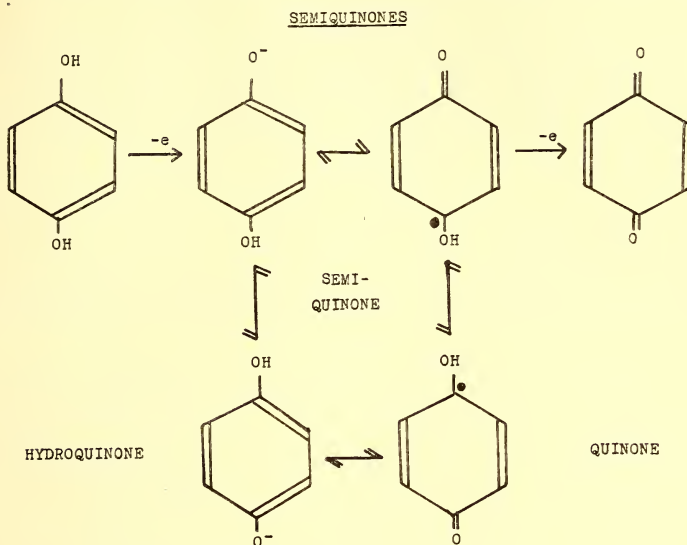
Fig. 3.—Semiquinones.

or HO radicals are released. This is the reaction the mechanism of which is still least understood. Warburg uses the analogy of hæmoglobin which binds oxygen to its ferrous iron, and which is oxidised to ferric hæmoglobin. But not only is this last reaction very slow, its mechanism is equally little understood.

DISSOCIATION CONSTANTS

Substrate-enzyme	Alcohol dehydrogenase—alcohol	10^{-2}
	,, ,, acetaldehyde	10^{-4}
	Zwischenferment–glucose-6 ph.	10^{-2}
	Triose phos.-dehydrogenase–glyceraldehyde-3-ph.	5×10^{-5}
DPN-enzyme	Alcohol-dehydrogenase—DPN^+	10^{-4}
	,, ,, DPNH	3×10^{-5}
TPN-enzyme	Zwischenferment—TPN	10^{-5}
	Flavoprotein—TPN	10^{-5}
Flavin ph.-enzyme	Various	10^{-7} to 10^{-8}
	TPN–cyt. c. reductase	10^{-9}
Cytochromes	Hæm–protein	0

Fig. 4.—Dissociation constants.

The respiration of carbohydrates.

Much of the respiratory energy of organisms is derived by the oxidation of carbohydrates such as glucose or glycogen, in a reaction which for glucose can be summarised as

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6CO_2 + 6H_2O$$
$$\Delta F° = -674,000 \text{ cals.}$$
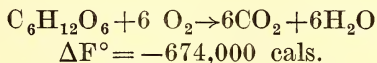
It is now known that the main path of this oxidation consists of two parts. The first of these leads from glucose to two molecules of pyruvate in 10 reactions

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(11 from glycogen) each catalysed by a specific enzyme (Fig. 5). Apart from the missing reduction of pyruvate to lactate which occurs in anærobic glycolysis, the reactions are the same, and they resemble those of the alcoholic fermentation in yeast. Many workers have contributed to the unravelling of this process but the names of Harden and Young, Embden and Meyerhof must be mentioned as those of the pioneers. The second part consists in the cyclic oxidation of pyruvate to carbon dioxide and water in the citric acid cycle, which will be discussed later. Only one of the reactions leading to pyruvate is an oxidative one, that which leads from 3-phosphoglyceraldehyde with incorporation of inorganic phosphate to 1·3-diphosphoglycerate. This involves the reduction of
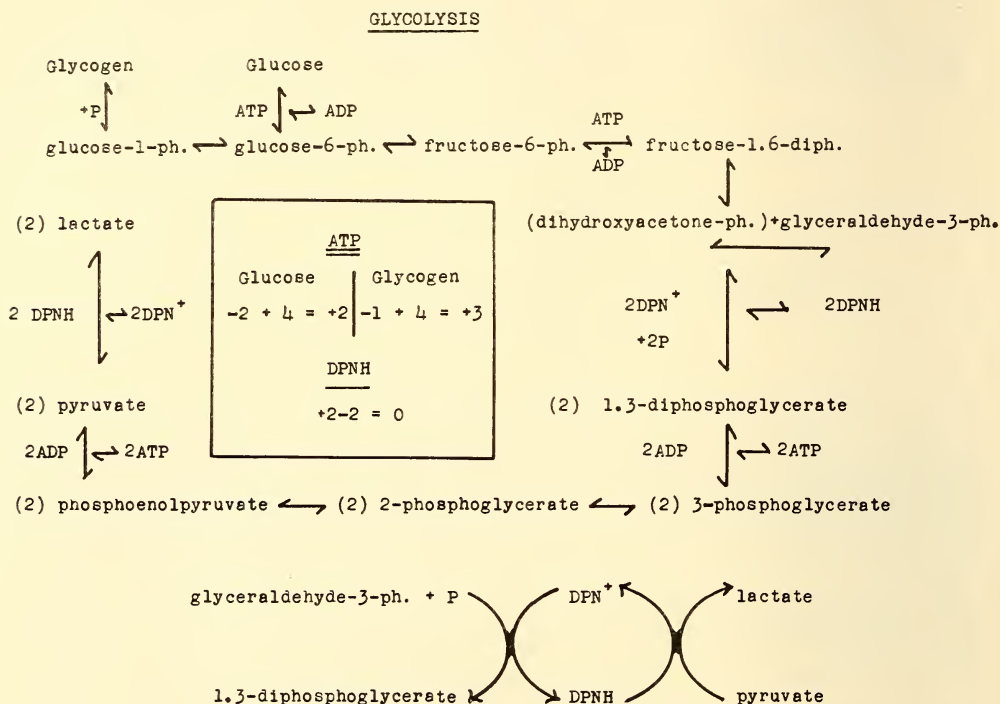
Fig. 5.—Glycolysis.

diphosphopyridine (which in glycolysis is oxidised back by pyruvate, with the formation of lactate). The other reactions consist either in isomerisation or in a transfer of phosphate groups to other positions. What is the meaning of this complexity ?

It is here where Lipmann's concept proves first helpful. As will be shown later, a great deal of the energy of the oxidation of pyruvate is transformed into the potential energy of the adenosine triphosphate (ATP) molecule. While the hydrolysis of normal alkylphosphate bonds yields a free energy ($-\Delta F^\circ$) of only about 3000 cals. per mole, that of certain other easily hydrolysable phosphate bonds, e.g. polyphosphate, carboxylphosphate, or enolphosphate bonds yields far higher free energies of 11,000–16,000 cals. per mole (Fig. 6). Conventionally the former bonds are written as R-ph, the latter, the " energy-rich" phosphate bonds as R~ph. Adenosine triphosphate is the most important of these compounds and provides the free energy currency.

The carbohydrate is first " primed " by the influx of two such " energy-rich " phosphate bonds making it ready for the split of the 6-carbon chain into two 3-carbon chain compounds interconvertible by a special enzyme (Fig. 5. This loss of ATP is then restored by the oxidative step which creates two energy-rich carboxylphosphate bonds in the two molecules of diphosphoglycerate which are transferred back to ADP. Two further " energy-rich " enolphosphate bonds then appear in the form of 2 molecules of phosphoenolpyruvate and are again transferred to ADP. A positive balance of two molecules of ATP thus remains. This free energy gain amounts to about 24,000 cals, or about 50% of the total free energy of the glycolytic reaction. In the formation of two molecules of pyruvate 6 additional ∼ph bonds are formed by the process of oxidation of two molecules of diphosphopyridine nucleotide in the oxidative phosphorylation discussed below.

The further oxidation of pyruvate to the end-products, carbon dioxide and water occurs in the citric acid cycle (tricarboxylic acid cycle or Krebs cycle). Szent-Gyorgyi carried out the first suggestive experiments, but the cycle was mainly worked out by Martius and Krebs. Pyruvate enters the cycle after

" ENERGY-RICH " PHOSPHATE BONDS (∼ph)

Adenosine triphosphate	Ad-ph∼ph∼ph	—12,000
Creatine- and arginine-phosphate	—N∼ph	—12,000–13,000
1·3-diphosphoglycerate acetylphosphate }	$-C\overset{\displaystyle /\!\!/O}{\underset{\displaystyle \backslash O\sim ph}{}}$	—16,000
Phosphenoenolpyruvate	$-C-O\sim ph$ $\parallel$ C	—16,000
" Normal " phosphate bond	RO—ph	—3,000

Fig. 6.—" Energy-rich " phosphate bonds (∼ph).

conversion into acetyl-coenzyme A by condensation with the 4-carbon compound oxalacetic acid, forming the 6-carbon compound citric acid. The somewhat simplified scheme of Fig. 7 shows that in one turn of the cycle one molecule of pyruvate is completely oxidised to carbon dioxide and water. Three molecules of carbon dioxide are formed, all by decarboxylation reactions. None of the oxygen is used for the oxidation of carbon to carbon dioxide and indeed isotopic oxygen $^{18}O_2$ does not appear in the form of carbon dioxide. Three molecules of water enter the cycle and their oxygen appears in carbon dioxide. Their six hydrogen atoms together with four hydrogen atoms of pyruvic acid enter the final oxidative chain in five pairs of hydrogen (three through diphosphopyridine nucleotide, one through triphosphopyridine nucleotide, and one, that from succinate, into the cytochrome system, probably through a flavoprotein).

Experiments on oxidative phosphorylation which were mainly carried out by Lipmann, Ochoa and Lehninger have shown that about 3 molecules of adenosine triphosphate are formed by incorporation of inorganic phosphate into adenosine diphosphate for one atom of oxygen consumed (P/O ratio). The P/O ratio for succinate oxidation appears to be only 2, that for α-ketoglutarate oxidation is possibly 4. Thus 30 energy-rich phosphate bonds are formed in the citric acid cycle oxidation of pyruvate, and 38 in the complete oxidation of glucose. The energy stored in these ∼ph bonds amounts to almost 70% of the total free energy available from glucose oxidation.

The free energies which become available in the stepwise oxidation of pyridine nucleotide via flavoprotein and the cytochromes can be roughly

calculated from their oxidation-reduction potentials and are in reasonable agreement with the P/O ratio (i.e. molecules of ATP formed per atom of oxygen consumed) found experimentally (cf. Fig. 8). No free energy sufficient to yield an " energy-rich " phosphate bond is available from the interaction between substrate and phosphopyridine nucleotide, or from that of cytochrome *c* with cytochrome *a*. The oxidation of phosphopyridine nucleotide by flavo-protein probably yields one, that of flavoprotein by cytochrome *c* a second,

CITRIC ACID CYCLE

$$C_3H_4O_3 + 3 H_2O \longrightarrow 3 CO_2 + 5 H_2$$
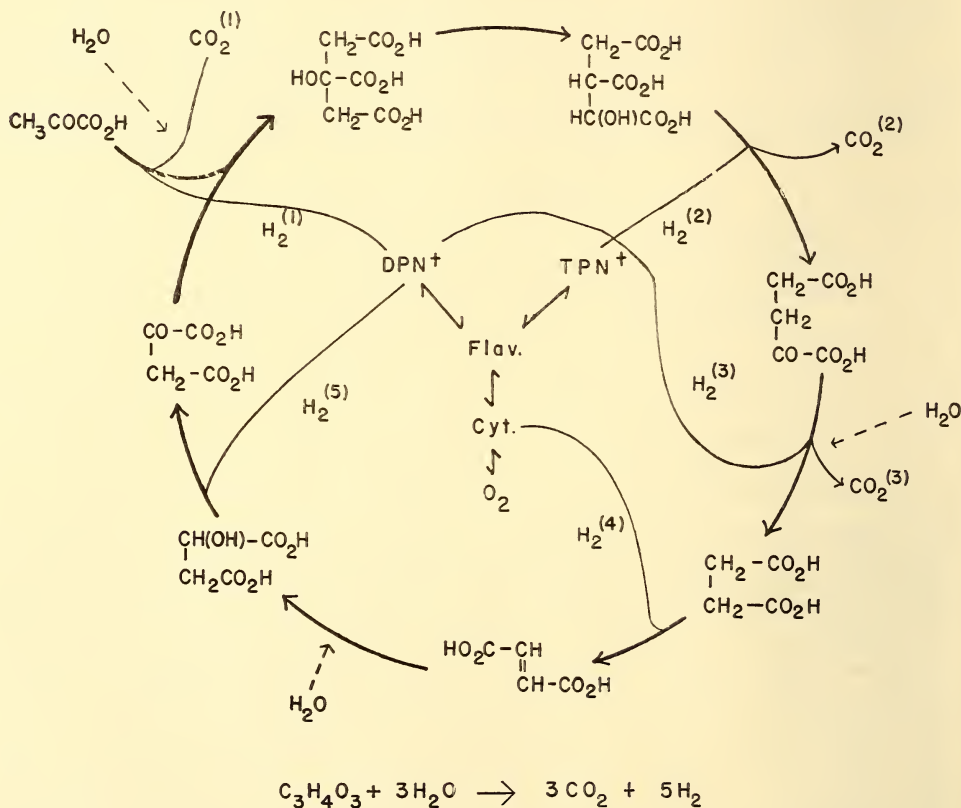
Fig. 7.—Citric acid cycle.

while the third is formed in the oxidation of cytochrome *c*, probably in the interaction of cytochrome oxidase with molecular oxygen. The free energy span between cytochrome *a* and oxygen would suffice for the formation of two " energy-rich " phosphate bonds, but the potential of the cytochrome oxidase which lies between cytochrome *a* and oxygen is still unknown. Experimentally the P/O ratio of this reaction has been found to be below one but it is difficult to measure. The mechanism by which energy-rich phosphate bonds are formed in these steps of the respiration chain is still unknown.

There is an intimate connection between the story of carbohydrate metabolism and the problem of conversion of the chemical potential energy of

adenosinetriphosphate into the mechanical energy of muscle contraction to which Meyerhof, Lohmann, Lundsgaard, A. V. Hill and D. M. Needham have made important contributions, and which has become even more interesting by the discovery of the interaction between adenosine, triphosphate and the contractible element of the muscle fibre, actomyosin (Engel'hardt, Szent-Gyorgyi, Straub).

OXIDATION-REDUCTION POTENTIALS

	E'_0, pH 7·0 ; V.	Δ	$\Delta F°$
O_2-water	+0·815		
Cyt. oxidase	?	0·52	—24,000
Cyt. a	+0·29		
Cyt. c	+0·255	0·04	— 1,900
Succinate-fumarate	0		
Cyt. b	—0·04	0·31	—14,300
Flavoproteins	—0·42 to —0·06		
Malate-oxalacetate	—0·10		
Lactate-pyruvate	—0·18	0·22	—10,200
Alcohol-acetaldehyde	—0·20		
DPN	—0·28		
TPN			
Isocitrate-oxalosuccinate	—0·30		
H–H^+	—0·42		

Fig. 8.—Oxidation-reduction potentials.

Energy-rich sulphur bonds.

In addition to energy-rich phosphate bonds energy-rich sulphur (thioester) bonds have been shown to be of particular importance. They have been first revealed by the work of Lipmann, Lynen and Ochoa on coenzyme A. Coenzyme A is required for the oxidation of fatty acids (see below) and for the oxidative decarboxylation of pyruvate and α-ketoglutarate. These reactions are peculiarly complex and involve another compound able to form energy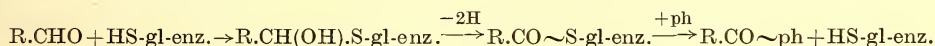-rich sulphur bonds, α-lipoic (or thioctic) acid. The acyl group remaining after decarboxylation (acetyl from pyruvate, succinyl from α-ketoglutarate, is first bound to lipoic acid, then to coenzyme A; thiamine pyrophosphate and magnesium are also necessary for these reactions.

Finally, the oxidative phosphorylation of 3-phosphoglyceraldehyde to 1·3-diphosphoglyceric acid is a particularly instructive example. It has also been shown by Racker to pass through a stage in which the aldehyde combines with glutathione bound to an enzyme. A thioacetal is thus formed. Its oxidation to the thioester creates an energy-rich sulphur bond and its exchange with phosphate leads to the energy-rich carboxylphosphate bond of 1·3-diphosphoglyceric acid. Thus Hopkins' glutathione has at long last found its place in cellular respiration.

$$R.CHO+HS\text{-}gl\text{-}enz.\rightarrow R.CH(OH).S\text{-}gl\text{-}enz.\xrightarrow{-2H} R.CO\sim S\text{-}gl\text{-}enz.\xrightarrow{+ph} R.CO\sim ph+HS\text{-}gl\text{-}enz.$$

Vitamins and cellular respiration.

I can discuss only very briefly the interesting relationships between vitamins and the groups active in cellular respiration (Fig. 9). Nicotinic acid is necessary for the formation of the pyridine nucleotides, riboflavin for that of the flavoproteins. Pantothenic acid is a constituent of coenzyme A. Lipoic acid and thiamine (in the form of its pyrophosphate) are necessary for oxidative decarboxylation. I shall not burden you with the chemical structures of these compounds which are far from simple.

The oxidation of fats and proteins.

It was known through Knoop's work that the oxidation of the fatty acids consists mainly in a breaking up into 2-carbon chains. Coenzyme A provided the key to the solution of this problem by Green, Lehninger and Lynen.

The oxidation of fatty acids like that of carbohydrate begins with a priming. Acyl-coenzyme A (acyl-Co A) is formed either by the action of ATP via acetyl-phosphate, or by other reactions such as exchange with succinyl-CoA, formed in the citric acid cycle. The acyl-CoA is then oxidised first by a flavoprotein

VITAMINS AS PROSTHETIC GROUPS

OF RESPIRATORY CATALYSTS

Nicotinamide	DPN, TPN	electron transfer
Riboflavin	-monophosphate and -adenine dinucleotide	" "
Pantothenic acid	coenzyme A	fatty acid oxidation
Thiamine-pyrophosphate		pyruvate → acetyl-Co A
α-Lipoic acid		α-ketoglutarate
		→ succinyl-Co A
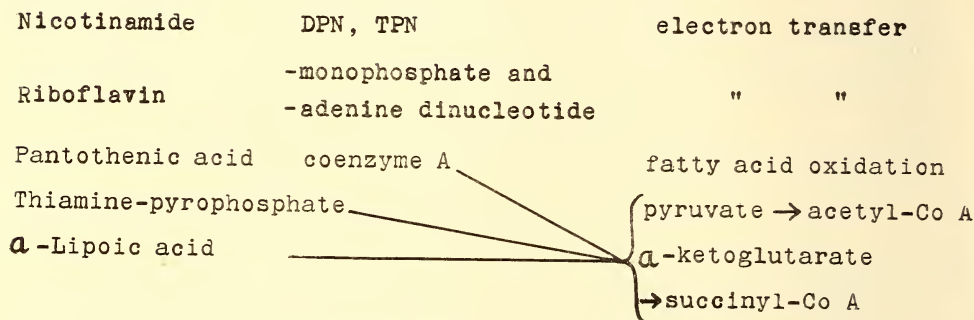
Fig. 9.—Vitamins as prosthetic groups of respiratory catalysts.

to the unsaturated acyl-CoA, and then after hydration further by diphospho-pyridine nucleotide to a β-ketoacyl-CoA. This is split by an enzyme with another molecule of coenzyme A to acetyl-coenzyme A and an acyl-coenzyme A with two carbon atoms less than the original. This reaction (β-oxidation) then

$$RCH_2CH_2CO{\sim}SCoA$$
$$\downarrow -2H$$
$$RCH{=}CHCO{\sim}SCoA$$
$$\downarrow +H_2O$$
$$RCHOHCH_2CO{\sim}SCoA$$
$$\downarrow -2H$$
$$RCOCH_2CO{\sim}SCoA$$
$$\downarrow +CoA$$
$$RCO{\sim}SCoA+CH_3CO{\sim}SCoA$$
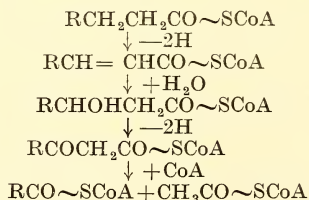
proceeds a second time etc. Acetyl-coenzyme A enters the citric acid cycle by condensation with oxalacetate and the two carbons of its acetyl group are thus oxidised to carbon dioxide and water.

With regard to the oxidation of proteins I restrict myself to pointing out that a number of amino-acids are easily converted to compounds of the citric acid cycle, thus glutamate and proline to α-ketoglutarate; aspartate to oxalacetate; alanine, cysteine, serine and glycine (via serine) to pyruvate, while other amino-acids require somewhat more complicated reactions.

The organelles of cellular respiration.

The particulate nature of cytochrome oxidase was soon recognised. Important evidence for a higher degree of organisation of the multitude of enzymes required in such complex mechanism came then from the work of Dixon and of D. E. Green.

Small rodlike particles ($0\cdot5-7\mu$ long), the mitochondria, can be observed microscopically in the cytoplasm (Benda). These can be obtained free from the nucleus, the cytoplasmic fluid, and smaller particles, the microsomes, by differential contrifugation in certain media (Claude, Hogeboom, Schneider). It is of particular interest for us that practically all the respiratory enzymse, cytochrome oxidase and the enzymes of the respiratory chain, the enzymes of the tricarboxylic acid cycle and of fatty acid oxidation, are found in the mitochondria. Even easily soluble compounds such as cytochrome c, the pyridine nucleotides, adenosine triphosphate, even orthophosphate appear to be present in the mitochondria in bound form. The mitochondria thus represent the respiratory organelles of the cell. They are particularly rich in phospholipid (20–25 %).

Electron microscope studies have revealed a complicated internal structure with an outside membrane, about 160 A thick and internal ridges, in which protein and lipid layers appear to alternate. The chloroplasts of green leaves, the photosynthetic centres, have a similar lamellated protein-lipid structure. It may thus not be accidental that both chlorophyll and hæm a, the prosthetic group of cytochrome oxidase, have lipoid character. Willstätter found that chlorophyll is a wax, i.e. an ester with the long chain alcohol phytol. The building principle of hæm a is different, since it contains a long alkyl side chain directly on the porphyrin ring, as recent work of Warburg and myself has shown. These lipophilic groups may well serve to anchor these molecules at the lipid protein interfaces of the lamellæ in mitochondria and chloroplasts.

The hæmatin catalysts and their biosynthesis

The role of hæmoproteins in the cytochrome system is not their only role in cellular respiration.

From the point of view of their biological action they can be divided into five classes :

1. *Oxygen carriers*, like hæmoglobin and myoglobin, in which oxygen combines reversibly with the ferrous iron without oxidising it to ferric. These compounds are only indirectly concerned with cellular respiration. Hæmoglobin brings oxygen as molecular oxygen close to the cells, and the myoglobin of red muscles is a temporary buffer of oxygen tension inside the muscle cell.

2. *Oxidases*, particularly cytochrome oxidase, which are autoxidisable and act as final carriers of electrons to molecular oxygen.

3. *Cytochromes*, which are not or only slowly autoxidisable ; they act as intermediate electron carriers with change of their iron valency ; Chance has recently greatly refined the study of the cytochrome system and other hæmatin enzymes by the use of highly sensitive and rapid spectrophotometric methods.

4. *Peroxidases*, which do not react with molecular oxygen but transfer electrons to hydrogen peroxide.

5. *Catalases*, which transfer electrons between two molecules of hydrogen peroxide, transforming them into oxygen and water ; under certain circumstances they can act as peroxidases.

In spite of the fact that catalases and peroxidases have been known for a long time and have been studied extensively with the result that a great deal is known on their mechanism of action, our knowledge about their biological function is still rather uncertain. Catalases are ubiquitous in ærobic cells ; peroxidases are generally found in plant tissues, but are more localised and restricted in animal tissues.

From the point of view of the chemical structure of the prosthetic group there are three main classes :

1. *Protohæm derivatives.* Protohæm is found not only in hæmoglobin and myoglobin, but also in the cytochromes *b*, in catalases, and in some peroxidases. Recently Chance and Smith have discovered a cytochrome oxidase with protohæm as prosthetic group in *Staphylococcus albus*. It is thus evident that the nature of the protein is of more decisive importance than that of the side chains of the porphyrin ring, and that the electronic configuration of the hæm iron is profoundly influenced by the nature of the attached protein and its type of linkage with the iron.

2. *Cytochrome c* and related cytochromes (f, c_1) which may be looked upon as protohæm compounds in which two molecules of cysteine of the proteic have been added to the two double bonds of protohæm, linking the prosthetin group firmly with the protein by thioether bonds.

3. *Cytochrome oxidase* (or cytochrome a_3) and cytochrome *a* which contains hæm *a*. The problem of the constitution of hæm *a* is the last great chemical problem of the hæm compounds. It is now nearing solution by work carried out in Warburg's and in my own laboratory (Lemberg, 1953, 1955). Hæm *a* has a formyl and at least one long alkyl side chain in addition to the usual ones. A similar formylporphyrin, but without a long alkyl side chain, forms the prosthetic group of chlorocruorin, an oxygen-carrying blood pigment of some worms. The formyl group has the effect of increasing the oxidation-reduction potential of the hæm. A possible role for the long alkyl group has been discussed above. Our recent work has made available a quantitative chemical method for the estimation in tissues which is of importance since the measurement of the particulate enzymes by their activity has many pitfalls. It may also help to solve the problem whether the enzyme is absent or only inactive in conditions in which the respiration is or becomes cyanide-insensitive, e.g. in unfertilized sea urchin eggs, or in diapauses.

Up to 1946 nothing was known on the biogenesis of the porphyrin and hæm compounds. In 1946 Rittenberg, Shemin and Bloch discovered that isotopic nitrogen of glycine and deuterium of deuteroacetate are incorporated into the hæm of hæmoglobin, and this enabled me to postulate a theory of biosynthesis of the porphyrins and hæmins from intermediates of the Krebs cycle such as α-ketoglutarate and succinic semialdehyde (Lemberg and Legge, 1949). A large part of the mechanism of this synthesis from succinyl coenzyme A and glycine via δ-aminolævulinic acid and porphobilinogen has now been worked out by the ingenious isotope work of Shemin, Neuberger, Rimington and Falk. Granick and others have shown that the biosynthesis of chlorophyll proceeds in the same way. There is no need to discuss this here, all the more since I have done it in other publications (Lemberg, 1955).

I must, however, point out one important consequence of these discoveries. The hæmatin enzymes are essential catalysts in the citric acid cycle, and yet are formed by it. Can we imagine a world without chlorophyll and hæmatin enzymes, in which the Krebs cycle was operative but without oxidative phosphorylation, or with a different mode of it ? Or can we assume an entirely different mode of hæm synthesis before the cycle became operative ? Neither assumption is intrinsically impossible, but for neither is there any evidence. How far can such speculations on biochemical evolution which are necessary for the extrapolation back to the origin of life on earth, still be called science ? I have pointed out previously (Lemberg, 1951) that similar difficulties appear if we consider the problem of the origin of life primarily from the aspect of the ability of self-multiplication found in viruses and genes, which for their multiplication require a great deal of the complicated cell metabolism. The

secret of life does not lie in the particular chemical structure of any substance, but in the marvellous interwovenness of the life processes.

In contemplating the glycolytic cycle, the Krebs cycle and the respiratory chain, I am reminded of the words of Goethe's Faust contemplating the sign of the macrocosm :

> Each to the Whole its substance gives,
> Each in the other works and lives !
> Like heavenly forces rising and descending
> Their golden pails one to the other handing.*

These words are equally true for the microcosm of the cell. Consider Faust's despair ? :

> How grand a show !
> But, ah, a show alone !—
> Where is the living force that feeds the Universe ?

How much further have we gone ? The show is grander than before. We may even get a glimpse of the nature of the forces rising and descending, and a very occasional glimpse at the fitness of a catalyst for its biological activity. Biochemistry has certainly progressed beyond mere analysis to an attempt at synthesis, however incomplete and patchy. The greater problems of the regulation of breakdown and synthesis, and of the correlation between molecular events and microscopic structure remain unsolved. We have learned that the single cell of the most primitive organism is, in fact, a microcosm, hardly less complex in its biochemical organisation than man.

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* Free after Bayard Taylor's translation.

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OCCULTATIONS OBSERVED AT SYDNEY OBSERVATORY DURING 1955.

By K. P. Sims, B.Sc.

(Communicated by the Government Astronomer.)

The following observations of occultations were made at Sydney Observatory with the 11½-inch telescope. A tapping key was used to record the times on a chronograph. The reduction elements were computed by the method given in the Occultation Supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there. The necessary data were taken from the *Nautical Almanac* for 1955, the Moon's right ascension and declination (hourly table) and parallax (semi-diurnal table) being interpolated therefrom. No correction was applied to the observed times for personal effect but a correction of $-0 \cdot 00152$ hour was applied before entering the ephemeris of the Moon. This corresponds to a correction of $-3'' \cdot 0$ to the Moon's mean longitude.

TABLE I.

Serial No.	N.Z.C. No.	Mag.	Date.	U.T.	Observer.
				h m s	
308	288	5·2	Jan. 3	9 31 27·2	R
309	611	7·0	Mar. 28	8 59 11·1	S
310	954	6·1	Mar. 30	9 42 29·6	S
311	956	6·3	Mar. 30	10 06 38·5	S
312	960	6·6	Mar. 30	11 08 43·2	S
313	962	7·0	Mar. 30	11 29 25·3	S
314	1241	6·4	Apr. 1	10 51 09·9	S
315	1458	5·9	Apr. 3	9 18 36·6	W
316	1845	6·5	May 4	8 50 26·3	S
317	1723	7·1	May 30	11 36 32·4	S
318	1788	6·7	June 27	11 37 23·7	S
319	2129	7·4	June 30	12 58 22·0	R
320	2595	5·7	July 31	10 04 57·6	R
321	——	7·3	July 31	10 21 38·0	R
322	2604	6·6	July 31	11 01 47·6	R
323	2608	6·9	July 31	11 26 10·4	R
324	2746	5·8	Aug. 1	9 57 10·4	S
325	2759	3·6	Aug. 1	12 43 45·0	S
326	2704	5·8	Aug. 28	12 01 00·3	R
327	2734	5·4	Oct. 22	10 20 01·4	S
328	3065	7·5	Nov. 21	9 03 48·8	S

Table I gives the observational material. The serial numbers follow on from those of the previous report (Sims 1955). The observers were H. W. Wood (W), W. H. Robertson (R) and K. P. Sims (S). In all cases the phase observed was disappearance at the dark limb. Table II gives the results of the reduction

which were carried out in duplicate. The N.Z.C. numbers given are those of the *Catalog of 3539 Zodiacal Stars for the Equinox* 1950·0 (Robertson 1940), as recorded in the *Nautical Almanac*.

TABLE II.

Serial No.	Luna- tion.	p	q	p^2	pq	q^2	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of	
										$\Delta\alpha$	$\Delta\delta$
308	396	+100	— 4	100	— 4	0	+0·3	+0·3	0·0	+13·8	+0·27
309	399	+ 76	—65	58	—49	42	—0·1	—0·1	+0·1	+11·4	—0·56
310	399	+ 92	+39	85	+36	15	0·0	0·0	0·0	+13·1	+0·28
311	399	+ 96	—29	92	—28	8	—0·5	—0·5	+0·1	+12·6	—0·39
312	399	+ 95	—30	91	—29	9	+0·1	+0·1	0·0	+12·5	—0·41
313	399	+ 76	—65	58	—49	42	+0·7	+0·5	—0·5	+ 9·4	—0·73
314	399	+ 78	—62	61	—49	39	+1·5	+1·2	—0·9	+ 8·1	—0·82
315	399	+ 87	+49	76	+43	24	—1·6	—1·4	—0·8	+14·7	+0·12
316	400	+ 82	—58	67	—47	33	+0·4	+0·3	—0·2	+ 8·1	—0·84
317	401	+ 77	—64	59	—49	41	+0·2	+0·2	—0·1	+ 6·8	—0·89
318	402	+ 55	—84	30	—46	70	+0·6	+0·3	—0·5	+ 2·9	—0·98
319	402	+ 97	+23	95	+22	5	—0·8	—0·8	—0·2	+14·1	+0·01
320	403	+ 82	+57	68	+47	32	—2·0	—1·6	—1·1	+10·6	+0·64
321	403	+100	+ 2	100	+ 2	0	+0·3	+0·3	0·0	+13·7	+0·11
322	403	+ 71	+71	50	+50	50	—0·1	—0·1	—0·1	+ 8·8	+0·77
323	403	+ 99	+13	98	+13	2	—0·2	—0·2	0·0	+13·5	+0·22
324	403	+ 91	—41	83	—37	17	—2·1	—1·9	+0·9	+13·5	—0·25
325	403	+ 97	—25	94	—24	6	—0·4	—0·4	+0·1	+14·0	—0·08
326	404	+ 43	+90	18	+39	82	—1·4	—0·6	—1·3	+ 4·0	+0·96
327	406	+ 43	+90	18	+39	82	—1·4	—0·6	—1·3	+ 3·8	+0·96
328	407	+ 63	+78	40	+49	60	—1·5	—0·9	—1·2	+ 5·0	+0·94

The star involved in occultation 321 was not in the *Nautical Almanac* list; it is G.C. 24543. Its apparent place is R.A. 17ʰ 59ᵐ 52ˢ·53, Dec. —22° 54′ 23″·8.

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THE SOUTH AUSTRALIAN EARTHQUAKE OF 1939 MARCH 26.

By K. E. Bullen
and B. A. Bolt.

Abstract.

Instrumental and macroseismic data from the South Australian earthquake of 1939 March 26 have been examined in considerable detail. The most probable position of the epicentre is 31°·8 S., 138°·0 E., and the most probable origin-time 3h. 56m. 5s. If this epicentre is correct (weaknesses in the instrumental data leave some margin of uncertainty), then it would appear that the phase S_n is not discernible on the Adelaide record (for which the epicentral distance is 3°·0), although the phases P_n, $P*$ and $S*$ have been recorded. On this interpretation the crustal structure of the region between the epicentre and Adelaide bears an important resemblance to the New Zealand region, where also the phase S_n has often gone undetected. A further point of practical importance is that unguarded use of $S-P$ intervals on seismograms recorded locally may possibly lead to serious overestimation of epicentral distances in Australia. These inferences are of course subject to the limitations of the present available seismological data in Australia, and it is suggested that they be further examined as suitable earthquakes occur.

I. Introduction.

On 1939 March 26, at about 1.30 p.m. local time, there occurred in South Australia an earthquake to which Gutenberg and Richter (1949) have assigned a magnitude of $5\frac{1}{2}$, corresponding, on their most recent formula, to an energy release of 10^{20} ergs. Gutenberg and Richter give the origin-time as 3h. 56m. 8s. (Greenwich civil time), and the epicentre as 31° S., 138° E. Certain local readings have been listed by de Jersey (1946), who states that the earthquake was felt at Marree; and various overseas readings as far distant as Harvard are recorded in the International Seismological Summary for 1939.

The earthquake is of special interest as being perhaps the first inland Australian earthquake of this magnitude to be recorded both within five degrees of a local station (Adelaide) and also at a number of overseas stations which can help in locating the epicentre. Through these features, the records of the earthquake are of possible significance to the problem of crustal layering in the Australian continent; and the purpose of the present paper is to examine the evidence from the earthquake in some detail with this problem in view.

Even in regions where the " density " of seismological observations is much higher than in Australia, the interpretation of near-earthquake records is subject to many uncertainties. Hence it is not to be expected that the analysis of the present paper will lead to precise results. A start has to be made somewhere on the difficult problem of crustal layering in Australia, and it is hoped that certain suggestions emerging from the present study may serve to guide studies based on evidence from future earthquakes.

II. Recorded Phases.

For bodily waves, the arrival-times of phases, in minutes and seconds after 3h. (G.C.T.), and the corresponding identifications, as quoted in the International Seismological Summary, are as follow :

Adelaide : 59m. 3s. (iP), 59m. 15s. (i), 59m. 18s., 59m. 26s., 59m. 46s., 59m. 53s. (iS).

Melbourne : 58m. 7s. (e), 58m. 43s. (i), 59m. 42s., 59m. 50s., 60m. 3s.

Riverview : 57m. 19s. (iE), 58m. 19s. (iN), 58m. 49s. (iE), 59m. 17s. (iN), 61m. 9s. (eN), 61m. 15s. (iE), 61m. 23s. (eZ), 62m. 0s. (iN), 62m. 4s. (iE), 62m. 29s. (iZ).

Brisbane : 59m. 0s. (eN) (de Jersey gives 58m. 59s. (iPN) for this onset).

Perth : 63m. 53s. (P), 64m. 7s. (PP), 64m. 23s. (PPP), 64m. 48s. (i), 65m. 15s., 65m. 50s., 65m. 58s. (S), 66m. 8s. (SS), 66m. 22s. (i).

Batavia : 63m. 32s. (PZ), 69m. 28s. (iSN).

Medan : 65m. 23s. (PEN), 72m. 43s. (eSE).

Colombo : 76m. 0s. (eE).

Kodaikanal : 77m. 0s. (eE).

Vladivostok : 67m. 49s. (iP), 77m. 26s. (iS).

Bombay : 67m. 21s. (eE), 78m. 21s. (eN).

Tashkent : 80m. 55s. (iS).

Baku : 86m. 0s. (e).

Sverdlovsk : 90m. 19s. (e).

Ksara : 74m. 46s. (e), 76m: 8s. (ePP), 85m. 56s. (ePS).

Mt. Wilson : 74m. 54s. (iPKPZ).

Riverside : 74m. 53s. (iPKPZ).

Tucson : 75m. 3s. (P).

Fordham : 75m. 59s. (i), 76m. 10s.

Harvard : 76m. 6s. (iZ).

III. Determination of Epicentre and Origin-Time.

A preliminary calculation showed that the normal P phase has not been recorded at stations other than Adelaide, Melbourne, Riverview, Brisbane, Batavia, Medan, Vladivostok and Bombay. The phase PKP has, however, been recorded at Ksara, Mt. Wilson, Riverside, Tucson, Fordham and Harvard. The determination of the epicentre must thus rest on a consideration of the recorded first onsets at these fourteen stations.

The epicentre and origin-time given by Gutenberg and Richter, namely

$$31° \text{S.}, \ 138° \text{E.} \ ; \ \ 3\text{h.} \ 56\text{m.} \ 8\text{s.} \ \ \ldots\ldots\ldots\ldots\ldots (1)$$

were used as a first approximation, the latitude being assumed to be geocentric. The direction-cosines of the epicentre in (1) are

$$a = -0 \cdot 6370, \ \ b = 0 \cdot 5736, \ \ c = -0 \cdot 5150. \ \ \ \ldots\ldots\ldots (2)$$

The geocentric angular distances Δ of the fourteen stations, as calculated using (2) with the formula $\cos \Delta = aA + bB + cC$, are shown in Table I. The azimuths which are not required accurately, were estimated by measurements on a globe. The observed P or PKP times in Table I correspond to first onsets quoted in Section 2, and relate to the origin-time in (1) as zero. The calculated times are based on the Jeffreys-Bullen tables (1948) for a surface focus, modified by allowances for the Earth's ellipticity (Bullen, 1937 and 1938) where needed. The last column of Table I shows the P or PKP residuals (Observed minus Calculated) for the various stations.

A feature of Table I is that the residuals for all overseas stations except Bombay are less than 10s. It was at first suspected that an error in counting the minute marks had been made at Bombay, but a communication from Dr. S. L. Malurkar indicates rather that the P onset is uncertain because of microseisms. (On the other hand, Dr. Malurkar tells us that the second impulse—which would be S—at 78m. 21s.—is " very clear and definite "). The first onset at Bombay was therefore not used in the epicentral determination.

In contrast to the overseas readings, the residuals at all the Australian stations are large.

The Adelaide record (N.-S. component, traced on a Milne-Shaw seismograph) is shown in Text-figure 1. It is obvious from the record that the identification of the first P onset could not be in error by the shown residual of 114 seconds. At a later stage of the investigation, information came to hand (from Drs. Gutenberg and Richter in California) that the Adelaide clock was two minutes fast over a period of time including the day of the earthquake. The residual in Table I therefore needs to be replaced by $-6\cdot3$ sec., but because of the clock error it seems unwise at this late date to attach high precision to the Adelaide absolute times. The Adelaide residual was therefore not used in the calculation of the present section.

TABLE I.

P *and* PKP *Residuals, Assuming Epicentre as* 31° S., 138° E., *and Origin-Time as* 3h. 56m. 8s.

Station.	Δ.	Az.	Observed P or PKP.	Calculated P or PKP.	O.—C.
			m. s.	m. s.	
Adelaide	3°·82	185°	2 55	1 1·3	+113·7
Melbourne	8°·81	150°	1 59	2 11·4	— 12·4
Riverview	11°·44	110°	1 11	2 47·7	— 96·7
Brisbane	13°·63	80°	2 52	3 17·0	— 25·0
Batavia	38°·34	305°	7 24	7 24·5	— 0·5
Medan	50°·96	300°	9 15	9 5·6	+ 9·4
Vladivostok	74°·14	355°	11 41	11 39·7	+ 1·3
Bombay	79°·93	295°	11 13	12 12·6	— 59·6
Ksara	115°·85	315°	18 38	18 43·7	— 5·7
Mt. Wilson	117°·35	70°	18 46	18 47·5	— 1·5
Riverside	117°·80	70°	18 45	18 48·4	— 3·4
Tucson	122°·39	80°	18 55	18 57·4	— 2·4
Fordham	152°·58	85°	19 51	19 51·2	— 0·2
Harvard	153°·90	85°	19 58	19 53·0	+ 5·0

The quoted Brisbane reading must also be rejected. The mean residual of the North American stations, which have about the same azimuth as Brisbane, is $-0\cdot5$ sec., and the dispersion about this mean indicates that it is accurate within less than 4 sec. In order to fit both the Brisbane and the North American readings it would then be necessary to shift the epicentre towards Brisbane through nearly two degrees, and such a shift, in addition to being unlikely on the macroseismic evidence, would clash with readings in all other azimuths. It appears therefore that Brisbane has read some movement before the arrival of the main shock. From letters since received from Dr. de Jersey and Dr. O. A. Jones, it would appear that the reading in question relates to a large microseism. Dr. Jones further informs us that he " would place an ePN at 3h. 59m. 22s., and, rather more doubtfully, an eSN at 4h. 1m. 42s." The ePN would yield the much-improved residual of $-3\cdot0$ sec. in place of $-25\cdot0$ sec.

in Table I, but was not used in the initial revision, which was confined to the routine readings reported in the International Seismological Summary; the reading will be referred to later.

Concerning the Riverview readings, Fr. Burke-Gaffney has informed us that the first two arrival-times quoted in Section II are " doubtful impulses ", previously referred to in the *Riverview Bulletin* as " perhaps only microseisms "; it is evident from Table I that the latter explanation is correct. Fr. Burke-Gaffney further states that " the impulse at 58m. 49s. is sharp enough, and the time may be taken as accurate within $\pm 0 \cdot 5$ second "; this is the reading which evidently corresponds to the quoted overseas readings. Thus in Table I it is necessary to replace the " observed " P time of 1m. 11s. for Riverview by 2m. 41s., and correspondingly to replace the residual of $-96 \cdot 7$ sec. by $-6 \cdot 7$ sec.
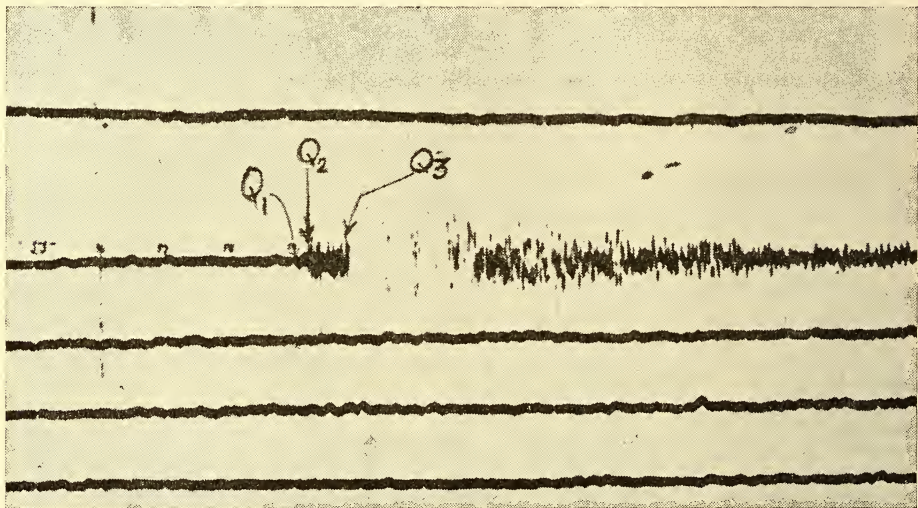
Text-fig. 1.—Adelaide seismogram of the earthquake of 1939 March 26.

The Melbourne residual, even though of magnitude 12 sec., is sufficiently close to the new Riverview residual to be usable, with Riverview, for a revised epicentral determination. The decision to use the Riverview and Melbourne readings is consistent with the high reliabilities, $1 \cdot 0$ and $0 \cdot 9$, respectively, assigned to these stations by Jeffreys (1937). (The reliability for Adelaide is given as $0 \cdot 6$; this means that the Adelaide P readings about this period were correct within ± 4 sec. on 60 per cent. of occasions. It may be remarked that in earlier studies of New Zealand earthquakes, one of the writers has found the Riverview readings to be uniformly reliable.) Dr. A. J. Gaskin informs us that the absolute time on the Melbourne record can be taken as reliable to within a second, but that the presence of microseismic activity would add some uncertainty to the identification.

Now let x and y denote the east and north angular displacements needed to the epicentre, and z the increase needed to the origin-time given in (1). Let T be the P (or PKP) travel-time, Δ the angular epicentral distance, ψ the azimuth, and μ the P (or PKP) residual for a given station or group of stations.

Equations were then formed of the type (Bullen, 1953)

$$(x \sin \psi + y \cos \psi)(dT/d\Delta) - z + \mu = 0. \quad \dots \dots \dots \dots \quad (3)$$

For Riverview and Melbourne, the equations obtained were

$$(x \sin 70° - y \cos 70°) \times 13 \cdot 6 - z = 6 \cdot 7, \quad \dots \dots \dots \dots \quad (4)$$
$$(x \sin 30° - y \cos 30°) \times 14 \cdot 0 - z = 12 \cdot 4, \quad \dots \dots \dots \dots \quad (5)$$

respectively.

For the four stations other than Bombay in the north-eastern quadrant, the residuals at Batavia and Vladivostok are in fairly good agreement, while Medan and Ksara though with roughly the same azimuth have numerically larger residuals. The two latter residuals being of opposite signs would, when appropriately weighted, hardly affect the calculation, and were ignored. The equations for the two former are

$$(-x \sin 60° + y \cos 60°) \times 8 \cdot 4 - z = 0 \cdot 5, \quad \dots \dots \dots \dots \quad (6)$$
$$y \times 5 \cdot 8 - z = -1 \cdot 3, \quad \dots \dots \dots \dots \quad (7)$$

respectively.

The North American stations were treated as a single group, since Δ and ψ are of the same order for all five stations and since it is the phase PKP which is recorded by them. A weighted mean residual of $-0 \cdot 7$ sec. was derived, weights being attached according to reliabilities assessed by Jeffreys (1937). The corresponding equation is

$$(x \sin 80° + y \cos 80°) \times 1 \cdot 8 - z = 0 \cdot 7. \quad \dots \dots \dots \dots \quad (8)$$

The equations (4), (5), (6), (7) and (8) were then used to determine x, y and z. It is not easy to decide how these equations should be weighted. *A priori*, the greatest weight should be given to the Riverview equation, but it transpired that a least-squares solution giving equal weight to all five equations led to values which fitted both the Riverview and Melbourne readings within a second. This was a satisfactory result and the procedure was therefore adopted. The normal equations corresponding to (4)–(8) were found to be

$$267x - 173y - 14 \cdot 2z = 169,$$
$$-173x + 219y + 6 \cdot 4z = -186,$$
$$-14 \cdot 2x + 6 \cdot 4y + 5 \cdot 0z = - 19 \cdot 0,$$

and yield

$$x = -0° \cdot 03, \quad y = -0° \cdot 79, \quad z = -2 \cdot 9s.$$

This solution gives the epicentre as

$$31° \cdot 8 \text{ S.,} \quad 138° \cdot 0 \text{ E.,} \quad \dots \dots \dots \dots \dots \quad (9a)$$

and the origin-time as

$$1939 \text{ March } 26d. \text{ 3h. 56m. 5s.} \quad \dots \dots \dots \dots \quad (9b)$$

In (9a) (and in Section IV), latitudes are geocentric ; the geographic latitudes would be greater by $0° \cdot 17$.

New epicentral distances and residuals were then calculated using (9), and the results are shown in Table II.

The determination leading to the results (9) is of course subject to more uncertainty than determinations for those larger overseas earthquakes for which there are a number of reliable readings in each of several azimuths. But comparison of Table II with Table I shows that the new epicentre yields appreciably smaller residuals, and is therefore to be preferred.

D

It may be added that Dr. Jones's *ePN* referred to earlier would give a residual of −2 sec. using (9), as against −3 sec. using (1). While Dr. Jones's reading therefore does not sharply discriminate between the epicentres in (9) and (1), the residual of magnitude 2 sec. is very satisfactory in view of the small amplitudes at the Brisbane distance.

Of further interest is a communication from Mr. R. C. Hayes, Director of the Dominion Observatory, Wellington (sent to us without knowledge of the new epicentral determination and after the completion of the above calculation). The routine Wellington bulletin had not reported any observations near 1939 March 26d. 4h., but Mr. Hayes writes that " there is a small impulse on the Wellington record which might be *P*, but it rather resembles the prevailing microseisms. All the movements are very small and might easily have been

TABLE II.

P *and* PKP *Residuals, Assuming Epicentre as* 31°·8 *S.,* 138°·0 *E., and Origin-Time as* 3h. 56m. 5s.

Station.	Δ.	Observed P or *PKP*.	Calculated P or *PKP*.	O.—C.
		m. s.	m. s.	
Adelaide	3°·00	2 58	0 50	+ 8
Melbourne	8°·19	2 2	2 2	0
Riverview ..	11°·22	2 44	2 45	− 1
Brisbane	13°·81	2 55	3 19	−24
Batavia	38°·79	7 27	7 28	− 1
Medan	51°·42	9 18	9 9	+ 9
Vladivostok ..	74°·94	11 44	11 44	0
Bombay	80°·33	11 16	12 15	−59
Ksara	116°·13	18 41	18 45	− 4
Mt. Wilson ..	117°·69	18 49	18 48	+ 1
Riverside ..	118°·14	18 48	18 49	− 1
Tucson	122°·67	18 58	18 58	0
Fordham	152°·97	19 54	19 52	+ 2
Harvard	154°·35	20 1	19 54	+ 7

overlooked in routine record scanning ". Mr. Hayes gives the times of the impulse as 4h. 2m. 25s., which would correspond to travel-times of 6m. 17s. or 6m. 20s., according as the origin-time is as in (1) or (9). The calculated distances of Wellington from the epicentres in (1) and (9) are 31°·1, 30°·75, respectively, yielding residuals of −5s. and +1s. Thus Mr. Hayes's reading confirms the revised epicentre and origin-time ; this result derives added significance from the fact that Wellington has a different distance and azimuth from all the other stations.

A further remark about the Adelaide reading is, however, necessary. The effect of the foregoing revision is to change the Adelaide residual from −6 sec. to +8 sec. This residual could be reduced to zero by taking an epicentre and origin-time nearly midway between (1) and (9a) ; this epicentre would be 0°·4 north of (9a). If an equation for Adelaide had been included in the least squares solution, the resulting epicentre would have been 0°·1 or 0°·2 north of (9a).

In all the circumstances, it would appear that the epicentre (9a) is likely to be accurate within about 0°·3.

IV. MACROSEISMIC DATA.

A surprising feature of the epicentre found in Section III is that it is located some 2°·4 south of Marree, where the earthquake had been reported as strongly felt in official accounts.

For this reason some considerable effort was made to assemble macro-seismic data, and questionnaires were sent to 90 centres within a radius of some 3 to 4 degrees from Marree. Because of the sparseness of the population in much of this part of Australia and because fifteen years had elapsed between the occurrence of the earthquake and the time at which the present investigation was undertaken, only limited information was obtained.

On collating replies to the questionnaires and various newspaper reports, it emerged that the earthquake was felt at points with (geocentric) latitudes ranging from that of Marree ($29°\cdot4$ S., $138°\cdot1$ E.) to that of Kadina ($33°\cdot8$ S., $137°\cdot7$ E.). At Marree the shock was felt by all residents, the post-office clock was stopped, and some small objects were overturned ; no damage was reported. The earthquake was also generally felt in Kadina, where residents were alarmed and feared that old mine workings had collapsed. The shock was described in Port Augusta ($32°\cdot3$ S., $137°\cdot7$ E.) as the largest felt for many years—" large buildings rocked and residents rushed into the streets ". At Port Pirie ($33°\cdot0$ S., $137°\cdot9$ E.), windows, doors and dishes rattled. The earthquake appears to have been strong enough to have disturbed or upturned small objects at centres north and south of Parachilna ($31°\cdot0$ S., $138°\cdot4$ E.), including Beltana, Blinman, Parachilna itself, Edeowie, Mern Merna and Hawker. The occupants of Motpena station near Parachilna state that every wall of the homestead was cracked ; they were greatly alarmed and felt thirteen aftershocks in addition to the main shock.

The westernmost point at which the shock was reported felt was Wirraminna ($31°\cdot0$ S., $136°\cdot2$ E.), and the easternmost (somewhat doubtfully) Mingary ($31°\cdot9$ S., $131°\cdot8$ E.). Other centres in which, according to reports received, the shock was at least strong enough to cause windows to rattle include Quorn, Bruce, Whyalla and stations at South Gap, Yalymboo, Roopeena and Arcoona.

It needs to be stressed that, since the population in the affected region is far from randomly distributed, it would be unwise to attempt to estimate the epicentre with any precision from the above macroseismic evidence. In particular, it would be unwise to attempt to use this evidence to discriminate between (1) and (9a).

The important inference can, however, be made that the new epicentre is fully consistent with the macroseismic data. Although, as pointed out above, the earthquake was reported as strongly felt at Marree, no evidence was received of it having been felt at any point further north. It would appear that the effects at Marree were accentuated by local alluvial conditions. The mean of the (geocentric) latitudes of Marree and Kadina is about $31°\cdot6$ S., which is within $0°\cdot2$ of the latitude in (9a). Moreover, most of the centres where the shock is reported to have been strongly felt have longitudes near $138°$ E.

V. Near-Earthquake Phases.

Although it was decided not to place great reliance on the absolute times at Adelaide, there is the possibility of using the intervals between the arrival-times of various phases at Adelaide to draw inferences on the local crustal structure.

In Text-figure 1, a reproduction of the Adelaide record is shown. The first onset can be clearly identified on the record within 1 or 2 seconds, and the arrival-time of 59m. 3s. quoted in the International Seismological Summary was found by the writers to be closely in accord with the time-marks on the record.

The first P onset on the record is denoted as Q_1 in Text-figure 1. Scrutiny of Text-figure 1 then shows that there are two further phases, denoted as Q_2 and Q_3, each accompanied by a sharp amplitude increase. (Q_3 is where the record

first becomes nearly invisible because of the large amplitudes.)   Careful measurement indicated that Q_2 and Q_3 arrived at time-intervals of 12 sec. and 48 sec., respectively, after Q_1, within errors of order 1 sec.   The three phases correspond fairly closely to the first, second and sixth readings quoted for Adelaide in Section II above.   The three other readings quoted in Section II do not correspond to noticeable amplitude changes, and it is highly doubtful whether they have any significance (in near-earthquake studies in other regions, significance is attached to such readings only when corresponding phases have been independently indicated at several other stations).

The phases Q_1, Q_2 and Q_3 are slender material to work on, but as it is unusual for an Australian mainland earthquake, for which an epicentral determination is available, ever to be centred within 5 degrees of an observatory, it is worth while examining the data in the light of experience which one of us has gained in analysing New Zealand near-earthquakes.

In Figure 1 of a previous paper (Bullen, 1939) is shown a set of tentative travel-time curves for part of the New Zealand region.   For an epicentral distance of $3°\cdot0$ (that shown for Adelaide in Table II), the arrival-times of near-earthquake phases (taking that of P_n as zero) are given as

$$P_n, \text{ 0s. ; }\quad P^*, \text{ 8--12s. ; }\quad P_{5\cdot0}, \text{ 21s. ; }\quad S_n, \text{ 36s. ; }\quad S^*, \text{ 47s. ; }\quad S_{3\cdot0}, \text{ 63s.}$$

The interesting result then emerges that the arrival-times of the Adelaide phases Q_1, Q_2 and Q_3 are in close agreement with those of the New Zealand phases P_n, P^* and S^*.   Further, it is also indicated that the phase quoted as iS for Adelaide in Section II is not S_n but S^*, the real S_n being not discernible.

The apparent absence of S_n on the Adelaide record may be compared with the finding (Bullen, 1938a) that in New Zealand earthquakes the phase S^* is not infrequently recorded when the normal S_n has been completely missed. If, then, the new epicentre (9a) is reliable to the extent indicated in Section III, it follows that the Australian region has an important feature in common with the New Zealand region in that there is evidence of relatively strong phases that would correspond to an " intermediate " layer.   The Adelaide record also gives no evidence of phases corresponding to the European P_g and S_g, which likewise are (at best) seldom recorded in New Zealand.   (P_g and S_g are here understood as phases for which the associated velocities are about $5\cdot6$, $3\cdot4$ km/sec., respectively.)   There are no phases on the Adelaide record corresponding to the New Zealand $P_{5\cdot0}$ and $S_{3\cdot0}$; but the latter are probably of local significance only and relate to the outermost few kilometres.

It needs to be emphasized that these various inferences from the Adelaide record are reliable only to the extent that the epicentre (9a) is preferable to the original epicentre (1) of Gutenberg and Richter.   If (1) were approximately correct, the phase Q_3 would probably in fact be S_n.   If the Adelaide residual were reduced to zero, making the epicentre midway between (1) and (9a), the inferences of the last two paragraphs would still stand, but less sharply.   The inferences would be upset if the Riverview and Melbourne readings were *both* in error to the extent of several seconds.   This is possible in the case of Melbourne, in view of what Dr. Gaskin writes, but unlikely in the case of Riverview.   The probability is, then, that the suggestions made in the two last paragraphs are fairly correct, but it is highly desirable that further evidence should be brought to bear as suitable new earthquakes occur.

However this question may be resolved in the future, a point of immediate practical importance emerges in that if, in Australian near earthquakes, S^* is misinterpreted as S_n, epicentral distances from local stations will be seriously overestimated.   One of us has shown that an earlier stage of seismological

investigation in New Zealand, misidentifications of this type had led to the locating of epicentres well out to sea when actually the foci were below the mainland.   In these circumstances it is advisable to regard epicentral estimations in Australia based on $S-P$ intervals as suspect until more is known about the first clearly-defined S phase.

VI. Readings of Phases Other than P.

An examination of readings not considered in Section III shows that a number of stations have recorded S phases.   Since most observers have found that S is in general " small or absent and sometimes more than 20s. late between

TABLE III.

S Residuals, Assuming Epicentre as 31° S., 138° E., and Origin-Time as 3h. 56m. 8s.

Station.	Δ.	Az.	Observed S.	Calculated S.	S. (O.—C.)
			m. s.	m. s.	s.
Perth	18°·9	250°	7 45	7 53	— 8
Batavia	38°·3	305°	13 20	13 19	+ 1
Medan	51°·0	300°	16 35	16 23	+12
Colombo	67°·2	290°	19 52	19 53	— 1
Kodaikanal	71°·1	290°	20 52	20 39	+13
Vladivostok	74°·1	355°	21 18	21 12	+ 6
Bombay..	79°·9	295°	22 13	22 16	— 3
Tashkent	96°·6	315°	24 47	24 47	0

distances of 5° and 15° " (see Lehmann, 1953), consideration of S readings has been limited to those from the eight stations which have recorded S at distances exceeding 15°.   In Tables III and IV the residuals are shown using the epicentre and origin-time (1) and (9), respectively.

TABLE IV.

S Residuals, Assuming Epicentre as 31°·8 S., 138° E., and Origin-Time as 3h. 56m. 5s.

Station.	Δ.	Observed S.	Calculated S.	S. (O.—C.)
		m. s.	m. s.	s.
Perth	18°·8	7 48	7 50	— 2
Batavia	38°·8	13 23	13 27	— 4
Medan	51°·4	16 38	16 29	+ 9
Colombo	67°·5	19 55	19 57	— 2
Kodaikanal ..	71°·4	20 55	20 43	+12
Vladivostok ..	74°·9	21 21	21 21	0
Bombay	80°·3	22 16	22 20	— 4
Tashkent	96°·6	24 50	24 52	— 2

In Table III the residuals for stations in azimuths near 300° are in fair agreement, apart from those for Medan and Kodaikanal ; taken in conjunction with the negative residual at Perth and the positive residual at Vladivostok, these residuals suggest an epicentral shift with a southerly component and of magnitude at least 0°·4.   The residuals in Table IV are better than those in

Table III, especially in the case of Perth and Vladivostok, and do not significantly suggest any epicentral change from (9a); they do, however, suggest an origin-time earlier by about two seconds. The net result of Tables III and IV is thus to give some small added support to the conclusion of Section III that the epicentre in (9a) is better than the epicentre in (1).

Certain other readings quoted in Section II can be associated with particular phases. Referred to (9), they can be summarized as follows :

Perth (18°·8) : SS —13s., SS +3s., SSS +15s. (or PcP —8s.).
Baku (108°·6) : PPS +31s.
Sverdlovsk (109°·8) : SS—17s.
Ksara (116°·1) : PP +13s., PS +19s.

Surface waves were recorded outside Australia at Vladivostok, Tashkent, Sverdlovsk, Pasadena and Tiflis.

VII. Acknowledgements.

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Department of Applied Mathematics,
University of Sydney.

6–COVALENT COMPLEXES WITH ACETYLACETONE AND BIVALENT METALS.

By F. P. DWYER, D.Sc.,
and A. M. SARGESON, B.Sc.,

ABSTRACT.

A series of alkali metal trisacetylactonate metal II compounds have been prepared by mixing methanolic solutions of the metal acetate and the alkali metal acetylacetonate. Evidence is adduced to show that the metal atom is 6-covalent. Replacement of one molecule of acetylacetone is easily effected in aqueous solution by addition of bases such as pyridine or 1 : 10-phenanthroline, and 6-covalent neutral complexes result.

Sodium tris-acetylacetone cobaltate II was prepared originally in poor yield by Rosenheim and Garfunkel (1911) by heating a mixture of sodium acetylacetone and sodium hexanitrocobaltate III. The substance is of especial interest since bivalent metals have been found usually to form bis complexes with acetylacetone. The question thus arises as to whether the metal atom is 6-covalent or the solid substance is merely a stoichiometric mixture of the bis compound and sodium acetylacetone.

The sodium and potassium salts can be obtained in almost quantitative yield by simply mixing cold methanolic solutions of cobalt II acetate and the alkali metal acetylacetonate, when crystalline precipitates separate immediately. The reaction is of general applicability and analogous compounds $Na[M(aca)_3]$, with nickel, iron II, manganese II, zinc, cadmium and magnesium can be obtained. Whilst this work was in progress, Van Uitert, Fernelius and Douglas (1953), in the course of the determination of the dissociation constants of bivalent metal complexes with acetylacetone in aqueous dioxane solution, noted the formation of crystalline precipitates. All seemed to contain one molecule of dioxane and the ratio Na : metal : chelate was found to be 1 : 1 : 3. These authors were non-committal on the mode of attachment of the third molecule of acetylacetone, but suggested from their titration studies that probably the ion $M(aca)_3^1$ had no existence in solution. In a subsequent paper the determination of the third dissociation constant will be described and hence the metal must be considered 6-covalent.

The absorption spectrum of the cobalt II compound is shown in Text-fig. 1, with the bis compound for comparison, and it would appear that in methanol solution a species other than the bis compound exists.

The equivalent conductivities of the cobalt II and iron II compounds in M/1000 methanol solution of 94 and 88 ohms^{-1} are consistent with uni-univalent electrolytes, but a mixture of the bis compound and sodium acetylacetonate would give the same result.

The magnetic moments indicate " ionic " or upper orbital bonding for the Co II, Mn II, Fe II and Ni compounds. The high moment of 4·75 B.M. for the cobalt compound as compared with 3·9 B.M. for the bis compound and

moments of the same order for " ionic " 4-covalent Co II must be due to a very large orbital contribution, which can be attributed to octahedral bonding (Nyholm, 1955).

It is significant that the third molecule of acetylacetone can be replaced easily in aqueous solution in the cold by the addition of phenanthroline, pyridine or ammonia, and the resulting complexes are undoubtedly 6-covalent.

All of the sodium and potassium tris compounds were easily soluble in water, with rather rapid separation of the insoluble bis compound. The iron II and manganese II compounds absorbed oxygen in the solid state and in solution yielding mixtures of the bi and tervalent neutral complexes, but the cobalt II compound did not oxidize in the air, and only very slowly by addition of hydrogen peroxide. Silver ion was effective as an oxidant.
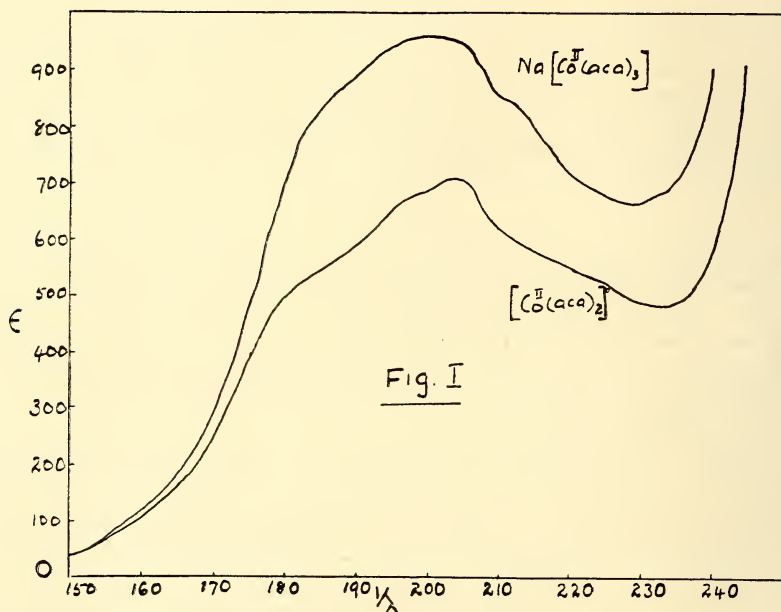
Fig. 1.

COMPLEXES CONTAINING ACETYLACETONE AND ANOTHER LIGAND.

Some complexes containing acetylacetone and two molecules of ammonia or pyridine have been described previously : $M(aca)_2(NH_3)_2$ or py_2 ; $M=Co^{II}$, Ni^{II} by Biltz and Clinch (1904) ; and $Mn(aca)_2(NH_3)_2$ by Emmert, Gsott-schneider and Stanger (1936). These have been obtained by reaction between the bis compound and the base. Pyridine, ammonia, 1 : 10, phenanthroline and 2 : 2, bipyridine reacted rapidly with the sodium tris chelate compounds and the non-electrolytic 6-covalent compounds usually separated immediately from solution. Direct reaction between, for example, phenanthroline and the bis compound gave the same result.

The following series have been prepared :

$M(aca)_2.(NH_3)_2$—M=Co, Mn, Zn, Cd, Mn, Mg.
$M(aca)_2.py_2$—M=Co, Ni.
$M(aca)_2.phen$—M=Co, Ni, Zn, Cd, Mn, Mg.
$M(aca)_2.dipy$—M=Co, Ni, Zn, Cd, Mn.
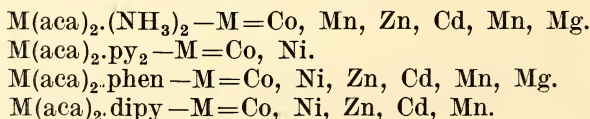
The bis-pyridine and diammine derivatives slowly lost the base on standing in the air, but the phenanthroline and bipyridine compounds were quite stable. The order of stability appeared to be $NH_3 < py < bipy < phen$. A qualitative assessment of the rate of dissociation of the phenanthroline from the complexes was obtained by spectrophotometric comparison of the rates of formation of the red ion $Fe(phen)_3^{++}$ when $M/1000$ solutions of the various metal complexes in 20% aqueous methanol were allowed to stand in the presence of a small amount of ferrous ion. The rate of loss of phenanthroline increased in the order $Ni < Co < Zn < Cd < Mn < Mg$.

The bonds in the substances $M(aca)_2.phen$ were ionic—the moments of the Ni, Co and Mn compounds being respectively $3 \cdot 12$, $4 \cdot 70$ and $6 \cdot 2$ B.M. The large moment of the cobalt compound can be regarded as significant of the octahedral bonding.

Special interest attaches to the 6-covalent magnesium complexes, since this element is usually 4-covalent. The hexammine $MgCl_2 6NH_3$ is known (Sidgwick, 1950), but the covalence in $Mg(phen)_4(ClO_4)_2$ (Pfeiffer and Christeleit, 1938) is probably not eight. It is possible that one or two phenanthroline molecules can be held in the solid lattice by Van der Waal's forces (Brandt, Dwyer and Gyarfas, 1954).

EXPERIMENTAL.
Sodium Tris-acetylacetone Cobaltate II.

Cobalt II acetate ($2 \cdot 5$ g. in 30 mls. of cold methanol), was added to cold methanolic sodium acetylacetonate, prepared from sodium hydroxide ($1 \cdot 3$ g. in 3 mls. of water), and acetylacetone ($3 \cdot 2$ g. in 50 mls. of methanol). The substance separated immediately as fine pink crystals, which were dissolved in methanol and reprecipitated with ether. It was slightly soluble in ethanol, very soluble in water, but insoluble in chloroform or benzene. These properties are characteristic of the whole series.

Found : $C = 47 \cdot 7$; $H = 5 \cdot 8$; $Co = 15 \cdot 4\%$.
Calculated for $Na[Co(C_5H_7O_2)_3]$: $C = 47 \cdot 49$; $H = 5 \cdot 58$; $Co = 15 \cdot 55\%$.

Potassium Tris-acetylacetone Cobaltate II.

Prepared in a similar manner to the sodium salt above gave red laths from methanol and ether.

Found : $C = 45 \cdot 3$; $H = 5 \cdot 5$; $Co = 14 \cdot 95\%$.
Calculated for $K[Co(C_5H_7O_2)_3].H_2O$: $C = 45 \cdot 51$; $H = 5 \cdot 35$; $Co = 14 \cdot 89\%$.

Sodium and Potassium Tris-acetylacetone Nickelate II.

Blue laths from methanol and ether. The substance was paramagnetic, $3 \cdot 20$ B.M.
Found : $C = 45 \cdot 4$; $H = 5 \cdot 9$; $Ni = 14 \cdot 65\%$.
Calculated for $Na[Ni(C_5H_7O_2)_3].H_2O$: $C = 45 \cdot 39$; $H = 5 \cdot 84$; $Ni = 14 \cdot 79$.
Found : $C = 45 \cdot 7$; $H = 5 \cdot 6$; $Ni = 14 \cdot 8$.
Calculated for $K[Ni(C_5H_7O_2)_3]$: $C = 45 \cdot 61$; $H = 5 \cdot 36$; $Ni = 14 \cdot 86$.

Sodium Tris-acetylacetone Zincate.

White laths from aqueous ethanol.
Found : $C = 46 \cdot 5$; $H = 5 \cdot 5$; $Zn = 17 \cdot 00\%$.
Calculated for $Na[Zn(C_5H_7O_2)_3]$: $C = 46 \cdot 72$; $H = 5 \cdot 49$; $Zn = 16 \cdot 94\%$.

Sodium Tris-acetylacetone Magnesate.

White laths from aqueous ethanol. The substance hydrolysed extremely easily yielding magnesium hydroxide.

Found : $C = 52 \cdot 3$; $H = 6 \cdot 1$; $Mg = 7 \cdot 1\%$.
Calculated for $Na[Mg(C_5H_7O_2)_3]$: $C, 52 \cdot 29$; $H, 6 \cdot 14$; $Mg = 7 \cdot 06$.

Sodium Tris-acetylacetone Cadmate.

White needles from aqueous ethanol or methanol and ether.

Found : C=39·9 ; H=5·2 ; Cd=24·7%.
Calculated for Na[Cd($C_5H_7O_2$)$_3$].H_2O : C=39·98 ; H=5·14 ; Cd=24·94)%.

Sodium Tris-acetylacetone Manganate II.

Crystallized from methanol and ether in an atmosphere of nitrogen gave pale cream laths. The magnetic moment was 5·8 B.M.

Found : C=47·9 ; H=5·42 ; Mn=14·46%.
Calculated for Na[Mn($C_5H_7O_2$)$_3$] : C=48·03 ; H=5·64 ; Mn=14·64.

Sodium Tris-acetylacetone Ferrate II.

Ferrous chloride (2 g. in 30 mls. of methanol) with one drop of dilute hydrochloric acid and a little pure iron dust was warmed in the water bath, cooled and filtered rapidly into a cold methanolic solution of sodium acetylacetonate. The substance separated as fine red needles. The magnetic moment was 5·82 B.M.

Found : C=47·7 ; H=5·5 ; Fe=14·6%.
Calculated for Na[Fe($C_5H_7O_2$)$_3$] : C=47·96 ; H=5·63 ; Fe=14·85%.

Diammine Bis-acetylacetone Metal Complexes.

These were prepared (1) by adding concentrated ammonia carefully to saturated methanol or aqueous solutions of the sodium or potassium tris complexes above, or (2) by adding concentrated ammonia to a saturated solution of the bis compound in methanol, or (3) by mixing the metal acetate with two molecular proportions of acetylacetone in methanol and adding concentrated ammonia.

Co($C_5H_7O_2$)$_2$.(NH_3)$_2$—pink hexagonal plates.
Found : Co=20·0%.
Calculated : Co=20·24%.
Ni($C_5H_7O_2$)$_2$.(NH_3)$_2$—blue plates.
Found : Ni=20·29%.
Calculated : Ni=20·14%.
Mn($C_5H_7O_2$)$_2$.(NH_3)$_2$—pale yellow plates.
Found : Mn=18·96%.
Calculated : Mn=19·10%.
Cd($C_5H_7O_2$)$_2$.(NH_3)$_2$—white hexagonal plates.
Found : Cd=32·4%.
Calculated : Cd=32·6%.

Bis-pyridine-bis-acetylacetone Cobalt II.

Prepared by warming the sodium salt of the tris compound in aqueous pyridine. After crystallization from aqueous alcohol containing a little pyridine it gave orange prisms.

Found : N=6·8 ; Co=14·2.
Calculated for Co($C_5H_7O_2$)$_2$.(C_5H_5N)$_2$: N=6·75 ; Co=14·19%.

Bis-pyridine-bis-acetylacetone Nickel II.

Prepared in the same manner as the cobalt compound gave mauve prisms from aqueous alcohol and a little pyridine.

Found : Ni=14·0%.
Calculated for Ni($C_5H_7O_2$)$_2$.(C_5H_5N)$_2$: Ni=14·15%.

1 : 10,Phenanthroline and 2 : 2′,Bipyridine-Bis-acetylacetone Metal Complexes.

These were obtained (1) by adding one mole of phenanthroline or bipyridine in a little alcohol to saturated aqueous solutions of the sodium tris compounds and extracting with chloroform, or (2) warming the bis compound $M(aca)_2$ with the base in chloroform solution, or (3) warming the diammine derivative with the base in chloroform solution. After filtration, the chloroform solutions were treated with petroleum ether or ligroin and the crystalline solid recrystallized from chloroform by the addition of petroleum ether. The iron II and manganese II compounds were prepared in an atmosphere of nitrogen. The relative stabilities of the complexes have been discussed previously—but all were decomposed by dilute acid.

$Co(C_5H_7O_2)_2.C_{12}H_8N_2$—orange laths.
Found : $N=6\cdot3$; $Co=13\cdot4\%$; M.W. in camphor, 435.
Calculated : $N=6\cdot41$; $Co=13\cdot55\%$; M.W., 437.
$Ni(C_5H_7O_2)_2.C_{12}H_8N_2$—green hexagonal prisms.
Found : $N=6\cdot4$; $Ni=13\cdot3\%$.
Calculated : $N=6\cdot41$; $Ni=13\cdot43\%$.
$Zn(C_5H_7O_2)_2.C_{12}H_8N_2$—white laths.
Found : $N=6\cdot45$; $Zn=14\cdot6\%$.
Calculated : $N=6\cdot31$; $Zn=14\cdot73\%$.
$Mg(C_5H_7O_2)_2.C_{12}H_8N_2$—white laths and needles.
Found : $N=7\cdot05$; $Mg=6\cdot1$; M.W. in camphor, 431.
Calculated : $N=6\cdot96$; $Mg=6\cdot04\%$; M.W., 403.
$Cd(C_5H_7O_2)_2.C_{12}H_8N_2$—white laths.
Found : $N=5\cdot8$; $Cd=23\cdot1\%$.
Calculated : $N=5\cdot71$; $Cd=22\cdot90\%$.
$Mn(C_5H_7O_2)_2.C_{12}H_8N_2$—pale yellow laths.
Found : $N=6\cdot7$; $Mn=12\cdot6\%$.
Calculated : $N=6\cdot47$; $Mn=12\cdot68\%$.
$Co(C_5H_7O_2)_2.C_{10}H_8N_2$—red laths.
Found : $C=58\cdot3$; $H=5\cdot2$; $Co=14\cdot6\%$.
Calculated : $C=58\cdot12$; $H=5\cdot37$; $Co=14\cdot98\%$,
$Ni(C_5H_7O_2)_2.C_{10}H_8N_2$—green needles.
Found : $C=58\cdot1$; $H=5\cdot5$; $Ni=14\cdot8\%$.
Calculated : $C=58\cdot15$; $H=5\cdot37$; $Ni=14\cdot90\%$.
$Zn(C_5H_7O_2)_2.C_{10}H_8N_2$—white laths.
Found : $N=6\cdot7$; $Zn=15\cdot4\%$.
Calculated : $N=6\cdot68$; $Zn=15\cdot57\%$.
$Cd(C_5H_7O_2)_2.C_{10}H_8N_2$—white laths.
Found : $N=5\cdot84$; $Cd=24\cdot3\%$.
Calculated : $N=6\cdot00$; $Cd=24\cdot07\%$.
$Mn(C_5H_7O_2).C_{10}H_8N_2$—pale yellow prisms.
Found : $N=6\cdot8$; $Mn=13\cdot2\%$.
Calculated : $6\cdot85$; $Mn=13\cdot42\%$.

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Department of Chemistry,
  Sydney University.

THE VOLATILE OIL OF *BÆCKEA CITRIODORA* PENFOLD AND WILLIS.

By H. H. G. McKern,
F. R. Morrison
and A. R. Penfold.

ABSTRACT.

The examination of seven samples of the volatile oil obtained by the steam-distillation of the shrub *Bæckea citriodora*, endemic to northern coastal districts of New South Wales, has shown the principal constituent to be (+)-citronellal, present to the extent of 54% to 80%. Other compounds identified as being present are isopulegol, (+)-α-pinene and citronellol. Small quantities of unidentified esters also occur in the oils. Yields of oil varied from 0·33 to 0·74%.

Bæckea citriodora, a newly-established species of the family *Myrtaceæ*, and described by Penfold and Willis (1955) in this Journal, is a small woody shrub which grows to a maximum height of about 30 cm. It has a very limited range, and to date has been found only in the Richmond River and Port Macquarie districts of New South Wales. In the former district it occurs in small, isolated patches, whilst in the latter district it occurs scattered over a large area of hundreds of acres. It occurs invariably on grey, sandy soil, and is usually found on the open heathland, although it sometimes occurs on the dry land bordering swamps. Botanically, it lies close to *B. linearis* C. T. White, the oil from which has not yet been investigated.

Although citronellal was readily recognized as the major component of the oils distilled from early collections of this species, the difficulty in securing adequate material has delayed investigations as to the nature of the remaining constituents. However, through the assistance of Mr. D. K. Hammond of Taree, sufficient oil has now been obtained for this purpose.

In addition to (+)-citronellal (54–80%), isopulegol and a small quantity (5%) of citronellol have been identified. The principal terpene is (+)-α-pinene, present to the extent of 5% to 10%. The crude oils were almost colourless mobile oils, obtained in yields of 0·33 to 0·74% by steam-distillation of the whole shrub. Analytical data recorded for the crude oils are presented in Table I.

It is thus seen that the oil of *B. citriodora* closely resembles that of *Eucalyptus citriodora* " Type " and *Backhousia citriodora* Variety " A " described by Penfold *et al.* (1951). It is of interest to note, however, that whereas the citronellal isolated from *E. citriodora* " Type " is the racemic modification, that from *Bæckea citriodora* is as strongly dextro-rotatory as that from *Backhousia citriodora* Variety " A " is lævo-rotatory.

The natural occurrence of isopulegol, first observed by Penfold (1931) in the oil of *Leptospermum liversidgei* Variety " B " (where it is the chief con-

TABLE I.

Physico-Chemical Data for Crude Oils of Bæckea citriodora Penfold and Willis.

Locality.	Date.	Weight of Foliage, Pounds.	Oil Yield, per Cent.	d_{15}^{15}	α_D	n_D^{20}	Solubility in 70% W/W Alcohol, Vols.	Ester Number, Mg. KOH/g.	Citronellal Content, Per Cent.	Remarks.
Woodburn, N.S.W.	27/ 3/28	14	0·62	0·8636	+16·2°	1·4511	1·6	53·0	80	2·5% free alcohols ($C_{10}H_{18}O$).*
Woodburn, N.S.W.	14/ 6/39	8	0·33	0·8780	+16·9°	1·4604	1·9	—	—	
Woodburn, N.S.W.	14/ 7/39	17	0·45	0·8840	+15·33°	1·4644	—	—	64·9	
Woodburn, N.S.W.	6/ 5/42	5	0·34	0·8710	+17·0°	1·4573	—	—	78	
Evan's Head, N.S.W.	14/ 9/49	3	0·50	0·8794	+19·3°	1·4632	—	—	54	
Evan's Head, N.S.W.	16/ 9/49	228 grams	1·0	—	—	—	—	—	68	Oil-yield high due to distillation in cohobation-type apparatus.
Taree, N.S.W.	21/12/54	35	0·56	0·8783	+15·2°	1·4604	1·65	3·5	58·3	29% free alcohols $C_{10}H_{18}O$*. 0·4% free primary alcohols calculated as citronellol.†
Taree, N.S.W.	17/ 5/55	24·5	0·74	0·8696	+15·73°	1·4568	2·0	4·3	70·2	1·6% free primary alcohols calculated as citronellol.†

* Determined from ester number of acetylated oil with prior oximation.
† Determined by phthalic anhydride method.

stituent), has again been demonstrated in the freshly distilled oils of this species. The presence of more than 25% of isopulegol was found in the 21/12/54 sample.

Limited quantities of oil prevented the identification of the esters which in the two most recent samples amounted to only about 1% of the oil. It would appear, however, that considerable variation in ester content may be encountered, one sample (Woodburn 27/3/28) having an ester number as high as 53·0. A similar variable ester content has been observed in oils of *E. citriodora* type, ester numbers from 12 to 60 having been recorded (cf. Guenther, 1950).

EXPERIMENTAL.

All oils were obtained by steam-distillation of the whole shrub, either in glass- or tin-lined apparatus. Melting points are uncorrected.

(+)-*Citronellal*.—This aldehyde was obtained from the various crude oils through its bisulphite compound. This was then steam-distilled with sodium carbonate solution, and the separated and dried product distilled *in vacuo*. A typical preparation had b_9 85°–86° ; d_{15}^{15} 0·8550 ; n_D^{20} 1·4474 ; α_D^{20} +13·94°. Its semicarbazone ($[\alpha]_D^{20}$ +39·26° in chloroform) melted at 83°–84°, undepressed by authentic specimens of citronellal semicarbazone.

Isopulegol.—The crude oil (21/12/54 sample ; 50 ml.) was shaken at 15°–18° for 2 hours with a hydroxylamine solution. This solution was prepared by mixing a hydroxylamine hydrochloride solution (50 g. ; 125 ml. water) and a potassium carbonate solution (50 g. ; 125 ml. water) and filtering. The separated and dried oximated oil was fractionally distilled at 10 mm. pressure, fractions being collected as indicated in Table II. Fraction 3 (2 g.) yielded an *allophanate*, m.p. 219°, undepressed by admixture with an authentic specimen of isopulegyl allophanate.

TABLE II.

Fraction.	Boiling Range.	Volume, Ml.	d_{15}^{15}.	n_D^{20}.	α_D.
1	38°– 50°	2·5	0·8648	1·4665	+37·48°
2	50°– 88°	1·0	—	1·4704	—
3	88°–100°	6·0	0·9105	1·4721	+4·90°
4	100°–120°	1·0	—	1·4740	—
5	120°–129°	1·5	—	1·4802	+3·04°
6	129°–130°	10·0	0·9107	1·4803	—0·68°
7	130°–131°	12·0	0·9099	1·4757	—6·67°
8	131°–154°	8·5	0·9183	1·4763	—7·76°

(+)-α-*Pinene*.—On fractional distillation of 17/5/55 sample a first fraction (3·5 ml. ; 6% by volume) was collected over the range 38° to 60° at 8 mm. This had d_{15}^{15} 0·8600 ; n_D^{20} 1·4684 ; α_D +29·96°. This was united with fraction 1 (2·5 ml. ; 5% by volume) of the 21/12/54 oil and oxidized in the usual way with ice-cold neutral permanganate. An *acid* was obtained which yielded a *semicarbazone* of m.p. 204°, undepressed on admixture with an authentic specimen of pinonic acid semicarbazone of similar m.p.

Citronellol.—Fractions 5 and 6 of the 21/12/54 oil were united with the steam-distilled residue (4 ml.) from the fractional distillation of the 17/5/55 sample to give a total of 5 grammes. This was refluxed 2 hours on the steam-bath with equal weights of phthalic anhydride and benzene. After neutralization with 0·5N NaOH and extraction of unreacted matter with ether, the reaction-mixture was steam-distilled with excess NaOH to give 1 ml. of primary alcohol (n_D^{20} 1·4656) of rose-like odour. It yielded an *acid phthalic acid ester* whose *silver salt* melted at 125° to 126°,

undepressed on admixture with a specimen prepared from authentic citronellol. A quantitative estimation of primary alcohols in the 21/12/54 and 17/5/55 samples by the phthalic anhydride method (Guenther, 1948) gave results of $0\cdot38\%$ and $1\cdot60\%$ respectively.

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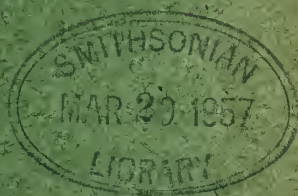GRIFFITH TAYLOR, d.sc., b.e., b.a.
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JOURNAL AND PROCEEDINGS

OF THE

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PART
II

1956

Edited by the Honorary Editorial Secretary

THE EPICENTRE OF THE ADELAIDE EARTHQUAKE OF 1954 MARCH 1.

By B. A. BOLT, M.Sc., F.R.A.S.

ABSTRACT.

The seismological evidence on the Adelaide earthquake of 1954 March 1 is discussed. A revised solution gives the epicentre as 34°·8 S., 138°·7 E., and the origin-time as 18h. 9m. 52s.

1. On 1954 March 1 there occurred near Adelaide, South Australia, a shock of sufficient magnitude to damage homes and buildings. A number of electric clocks were stopped in Adelaide City at times ranging from about 10 seconds before 3.40 a.m. up to 3.40 a.m. local time.

The March 1954 Bulletin of the Central International Bureau of Seismology gives a provisional epicentre of 35°·5 S., 138°·5 E., and an origin-time of 18h. 09m. 53s. (G.M.T.). This epicentre is shown as the point A in Text-figure 1. Data which have since become available indicate clearly that this epicentre needs a northerly displacement. The purpose of the present paper is to obtain an improved epicentre.

2. The arrival times of phases given in the above Bulletin, supplemented by times in the Station Bulletins of Brisbane and Perth are listed in Table I as times after 18 hours (G.M.T.), with the station identifications following in brackets.

TABLE I.

Melbourne :	11m. 20s. (*Pn*), 12m. 25s. (*Sn*).
Riverview :	12m. 26s. (*P*), 14m. 38s. (*iS*).
Brisbane :	13m. 15·5s. (*iP*), 16m. 14s. (*iS*), 17m. 20s. (*e*), 17m. 38s. (*i*).
Perth :	20m. 11s. (*i*), 22m. 23s. (*i*).
College :	28m. 31s. (*iPKP*).
Nelson :	28m. 47·2s. (*iPKP*).
Hungry Horse :	28m. 55s. (*iPKP*).
Tamanrasset :	29m. 07s. (traces), 29m. 25s. (*ePKP*).
Alger Univ.	30m. 02s. (*ePKP$_2$*).
Paris :	29m. 29s. (*ePKP*), 29m. 36s. (*i*).
San Juan :	29m. 48s. (*e*), 30m. 05s. (*i*).

Mr. C. Kerr Grant, of the South Australian Department of Mines, informs me that unfortunately no information can be obtained from the Adelaide record since not only was the Milne-Shaw seismograph thrown off the scale at the first onset but also the time-breaks had failed on the day of the shock. Also Mr. R. C. Hayes, Director of the Dominion Observatory, Wellington, informs me that the shock was not recorded in New Zealand, or at Apia. The relevant Station

E

Bulletins from Baguio and Manila, kindly made available by Fr. Burke-Gaffney, Director of the Riverview College Observatory, also show no readings.

The paucity of instrumentally recorded phases implies that the shock was of relatively small magnitude. This conclusion, taken in conjunction with the macroseismic evidence assembled by Mr. Kerr Grant that the shock had a maximum intensity of VIII on the modified Mercalli scale, suggests that the focal depth is slight. Mr. Kerr Grant writes that " the earthquake was very shallow and the depth of focus is certainly less than 10 km.".

3. Table II shows the geocentric angular distances Δ and azimuths Z of stations from the provisional epicentre (the latitude was assumed to be geocentric) and the residuals (O. —C.) for all the P and PKP readings. The calculated arrival-times were determined using the Jeffreys-Bullen tables for a surface focus (1948), corrected for ellipticity effects where necessary (Bullen, 1937). Table II

<div align="center">TABLE II.</div>

<div align="center">P <i>and</i> PKP <i>Residuals, Assuming Epicentre as</i> 35′ 30′ S., 138° 30′ E., <i>and Origin-time as</i>
18h. 9m. 53s.</div>

Station.	Δ	Az.	Observed Travel-time.	Calculated Travel-time.	O.—C.
			m s	m s	s
Melbourne	5°·68	116°	1 27	1 26·5	+ 0·5
Riverview	10°·55	85°	2 33	2 35·5	— 2·5
Brisbane	14°·73	61°	3 22·5	3 31·5	— 9·0
Perth	19°·17	255°	—	4 27·7	—
College	115°·14	27°	18 38	18 42·3	— 4·3
Nelson	121°·91	66°	18 54·2	18 56·4	— 2·2
Hungry Horse ..	126°·44	52°	19 02	19 04·7	— 2·7
Tamanrasset	137°·40	274°	19 32	19 26·3	+ 5·7
Alger Univ.	144°·24	285°	20 09	19 37·6	+31·4
Paris	145°·26	306°	19 36	19 39·0	— 3·0
			19 43	19 40·6	+ 2·4
San Juan	152°·33	122°	19 55	19 51·3	+ 3·7
			20 12	20 10·4	+ 1·6

shows a dependence between residual and azimuth. Stations to the north, except Tamanrasset and Alger Univ., show negative residuals, while Melbourne and San Juan to the south-east show positive residuals. This indicates that an epicentral displacement towards the north is required.

The residual at Alger Univ. is the only PKP residual exceeding 12 seconds. Also, although Δ and Z for this station and Tamanrasset are near the values for Paris, a station of the highest reliability (Lehmann, 1949), there is a large difference between their residuals and that of Paris. In the absence of other information it was therefore decided to ignore the readings at Alger Univ. and Tamanrasset. The residuals of the North American stations of College, Nelson and Hungry Horse are consistent ; their azimuths are similar and all show <i>impetus</i> onsets. It follows that the mean residual of this group should be weighted strongly. The remaining overseas stations of Paris and San Juan which lie approximately on the same great circle as Melbourne, have residuals in agreement with the residual of Melbourne. Thus the readings from Paris and San Juan can be combined consistently, making allowance for the known high reliability of Paris in the allocation of weights.

The readings at the Australian stations give residuals for the only P phases recorded, and these will be given greater weight than the overseas readings. The Brisbane residual is large compared with the others, and any change in the

position of the epicentre will be affected by the weight attached to the Brisbane reading.   Dr. O. A. Jones, of the University of Queensland, very kindly re-examined the Brisbane record and informs me that he has no doubt about the position of the P onset on the Benioff vertical-component record and that "it is unlikely that the clock correction was more than $0 \cdot 5$ sec. in error and impossible that it was 3 sec. wrong ".   On this evidence and from geographical and other considerations it would seem best to allot equal weight to the data from Melbourne, Riverview and Brisbane.   The recorded time of the first phase in Table I for Perth is 6 minutes late, and it follows that neither of the two recorded phases is relevant to the epicentral determination.   A re-examination of the original seismogram kindly made available to me by Mr. H. S. Spigl, the Government Astronomer in Western Australia, shows that no earlier onset is distinguish-
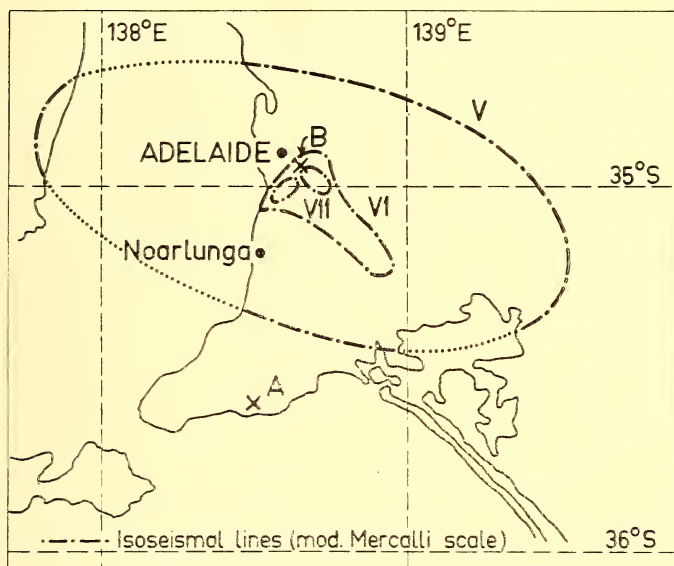
Text-fig. 1.

able.   The Perth seismograph is a N.-S. horizontal-component Milne-Shaw and is not well orientated to record a relatively small earthquake from the Adelaide region.

4. Let the needed corrections to the epicentre and origin-time be $x°$ north and $y°$ east and $+Y$ sec.   Then for a given station or group of stations of mean azimuth α and residual μ, Jeffreys and Bullen give the corresponding equation of condition as

$$Y - \left(\frac{d\tau}{d\Delta}\right)(x \cos \alpha + y \sin \alpha) = \mu \quad \dots\dots\dots\dots\dots \quad (1)$$

The following equations are then obtained from (1), using the data in Table II for (a) Melbourne, (b) Riverview, (c) Brisbane, (d) the three North American stations as a group, (e) Paris and San Juan, giving the Paris data twice the weight given to that of San Juan.

$$Y + 6 \cdot 18x - 12 \cdot 67y = +0 \cdot 5 \quad \dots\dots\dots\dots\dots \quad (a)$$
$$Y - 1 \cdot 20x - 13 \cdot 65y = -2 \cdot 5 \quad \dots\dots\dots\dots\dots \quad (b)$$
$$Y - 6 \cdot 35x - 11 \cdot 46y = -9 \cdot 0 \quad \dots\dots\dots\dots\dots \quad (c)$$
$$Y - 1 \cdot 26x - 1 \cdot 41y = -3 \cdot 1 \quad \dots\dots\dots\dots\dots \quad (d)$$
$$Y - 0 \cdot 42x + 0 \cdot 52y = -0 \cdot 8 \quad \dots\dots\dots\dots\dots \quad (e)$$

The least squares solution of these equations (which were given equal weight) is

$$x = 0°·75, \quad y = 0°·16, \quad Y = -1·31 \text{ s.}$$

The corresponding epicentre is at 34° 45′ S., 138° 40′ E., and the origin-time is 18h. 9m. 52s. The geographic latitude of the new epicentre which is shown by the point B in Text-figure 1 is 34° 56′ S.

5. In Table III, the revised epicentral distances and residuals are shown for the principal stations. The table shows a general improvement in the consistency of the residuals, indicating that the revised epicentre is probably much closer to the actual epicentre than the provisional epicentre.

TABLE III.

P and PKP Residuals, Assuming Recalculated Epicentre 34° 45′ S., 138° 40′ E., and Origin-time as 18h. 9m. 52s.

Station.	Δ	O.—C.
		s
Melbourne	5°·88	—2
Riverview	10°·40	+1
Brisbane	14°·36	—3
College	114°·57	—2
Nelson	121°·58	0
Hungry Horse	126°·00	0
Tamanrasset	137°·57	+6
Paris	145°·03	—1 E
		+4 A
San Juan	152°·51	+5 E
		+2 A

6. From a consideration of macroseismic evidence, Kerr Grant has estimated the epicentre at approximately 35° 2′ S. (geographic latitude), 138° 33′ E. His isoseismal lines are reproduced in Text-figure 1, which shows that the revised epicentre, which lies near the area of greatest damage, is much more in accord with the macroseismic data than the provisional epicentre of Section 1. Because

TABLE IV.

S-residuals for the Provisional and Revised Epicentres.

	Provisional.	Revised.
	s	s
Melbourne	—1	— 7
Riverview	+9	+14
Brisbane	+5	+14

of the strong probability that the shock was very shallow, this accord is to be expected. It may be significant that the Eden Fault line is within $1\frac{1}{2}$ miles of the revised epicentre. The uncertainty of the determination is, of course, greater than $1\frac{1}{2}$ miles.

7. S phases were recorded at Melbourne, Riverview and Brisbane. The S residuals for the provisional and revised epicentres are shown in Table IV.

Not much significance can be attached to these residuals.   But it may be remarked that the large positive residuals at Riverview and Brisbane accord with a systematic delay in S arrival times noted by Miss Lehmann (1953) for $5° < \Delta < 15°$.   This feature, incidentally, suggests that the use of $S–P$ intervals in determining distances of Australian stations from epicentres in the Australian Continent is unsatisfactory.   The negative Melbourne S residual is possibly associated with a P phase.

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FURTHER NOTES ON ORDOVICIAN FORMATIONS OF CENTRAL NEW SOUTH WALES.

By N. C. STEVENS.

With Plate I and one Text-figure.

ABSTRACT.

New fossil discoveries in the Cargo district suggest an Ordovician age for the major limestone beds, the Cargo Andesite and some sediments which overlie the limestones. Ordovician rocks (including limestone) at Bowan Park have been mapped and the sequence described and correlated with other Ordovician strata. East of Cliefden Caves a facies of the Malongulli Formation with members belonging to the greywacke suite has been examined. An account is given of the palæogeography of this area in Ordovician times.

I. INTRODUCTION.

Ordovician rocks are now known to outcrop over a large area south of Orange in Central New South Wales, and an Ordovician age has been proved for the fossiliferous limestones of Cliefden Caves (Stevens, 1952) and Bowan Park (Brown, 1952), previously considered Silurian. As the limestone at Bowan Park was in a similar stratigraphical position to the Cargo Creek Limestone overlying the Cargo Andesite (Stevens, 1950), a further search for fossils was made in the limestones and associated rocks south of Cargo, which showed greater resemblance to the Ordovician of Cliefden Caves than to the Silurian of Four Mile Creek (Stevens and Packham, 1953).

II. LIMESTONES OF THE CARGO DISTRICT.

Three lithologically similar limestone beds occur in the Parishes of Cargo and Canomodine, south and south-east of Cargo (Plate 1). Although they are approximately the same age, distinct names are given to each for ease of reference.

Regan's Creek Limestone. Three miles south-east of Cargo the easternmost and smallest bed overlies the Cargo Andesite and is faulted against graptolite-bearing strata of a higher horizon to the east, beside Regan's Creek (Stevens, 1950).

At the base of the northern outcrop are reddish limestones with brachiopods similar to those from the upper part of the lower member of the Cliefden Caves Limestone. In a similar position at the northern end of the southern outcrop, Dr. D. Hill has recognized *Palæoporites* sp., *Propora* sp., *Heliolites* sp., *Eofletcheria* sp. and ? *Lichenaria* sp., an assemblage which may be either late Middle or early Upper Ordovician. The more massive limestones above contain stromatoporoids, gastropods, *Propora* sp. and *Heliolites* sp.

Cargo Creek and Canomodine Limestones. Fossils are much less abundant in these, the main limestone beds. At the base of the Cargo Creek Limestone are shaley beds with *Propora* sp., and from a higher horizon west of Cargo Creek, *Propora* and *Plasmoporella* have been collected. These forms are also present

in the Canomodine Limestone, with stromatoporoids, streptelasmids and a possible *Lichenaria.*

The Canomodine Limestone dips off andesites on its south-west margin, and as the fossils and lithology are similar in Canomodine and Cargo Creek Limestones, the two formations are considered to be equivalent, either Upper Ordovician or Lower Silurian (Hill, 1955). The intervening formation of siltstones and arenites in the Cargo Creek area clearly overlies the Cargo Creek Limestone and appears to be faulted against the Canomodine Limestone, as graded bedding in the siltstones gives no evidence of overfolding.

Bowan Park Limestone. A large area of gently dipping limestone at Bowan Park occurs in the same stratigraphical position as the Cargo Creek Limestone, overlying Cargo Andesite (Table 1).

TABLE 1.

Correlation of Ordovician Formations in Central New South Wales.

			Cliefden Caves.	Canomodine.	Bowan Park.
Lower Silurian.		——	——	——	——
Ashgillian.	Zone of *Pleuro-graptus linearis.*			Millambri Formation.	Malachi's Hill Formation.
Caradocian.			Angullong Tuff.	—?————?—	—?————?—
Llandeilian.	Zone of *Nema-graptus gracilis.*		Malongulli Formation.	Cargo Creek and Canomodine Limestones.	Bowan Park, Barton and Regan's Creek Limestones.
			Cliefden Caves Limestone.		
? Llanvirnian.			Walli Andesite.	Cargo Andesite.	

(left margin label, spanning: Ordovician.)

On Paling Yard Creek (Portions 36 and 55, Parish of Bowan) a bed of brown felspathic sandstone 30 feet thick with abundant rhynchonellids is intercalated between andesitic breccias of the Cargo Andesite and the base of the limestone. At this place the basal limestones are thinly-bedded and marly with fragmentary brachiopods and gastropods, but most of the overlying limestone is massive, with occasional heliolitids and streptelasmids. Certain beds in Portion 289, Parish of Bowan are rich in brachiopods, corals and gastropods, with some bryozoa, stromatoporoids and nautiloids.

Dun determined *Trematospira, Naticopsis, Columnopora* (?), *Lophospira, Lituites, Heliolites* and *Hormotoma* from this limestone and remarked (in Andrews and Morrison, 1915) that "the Bowan Park Silurian fauna is quite different in its facies from those recorded from any other locality in the State".

Brown (1952) deduced an Ordovician age for the limestone from a study of the brachiopods, which include *Spanodonta, Tritœchia,* a syntrophopsid and an orthid. Species of *Propora, Heliolites* and *Eofletcheria* (determined by Dr. Hill) are the same as those found in the Regan's Creek Limestone. In addition, *Coccoseris* and dasycladacean algæ are known to be present.

The Bowan Park Limestone is probably equivalent to the Barton Limestone of Spring and Quarry Creeks to the north-east (Packham and Stevens,

1955), as the same species of *Coccoseris* and possibly of *Propora* is common to both (personal communication, Dr. Hill).

Other Limestones. Some miles west of Cargo, widely separated limestone lenses overlie the equivalent of the Cargo Andesite between Boree Creek and Barragan. They are mostly massive and unfossiliferous, but in the nothern-most outcrop (Portion 41, Parish of Boree Cabonne), the occurrence of *Calapœcia* suggests a Middle or Upper Ordovician age for these beds.

III. (?) ORDOVICIAN STRATA WHICH OVERLIE THE LIMESTONES.

(1) Millambri Formation.

The siltstones and sandstones overlying the Cargo Creek and Canomodine Limestones south of Cargo constitute the Millambri Formation ; the best exposures of these rocks are found along the Belubula River between "Millambri" and "Cranky Rock" properties. The formation conformably overlies the Canomodine Limestone and has been folded into a broad, plunging anticline so that it outcrops in a semi-circular belt around the southern end of the limestone.

Arenites (using the term in the same sense as Pettijohn, 1949), predominate in the lower part of the formation and banded siltstones in the upper part. The arenites contain sub-angular fragments of albite, pale green pyroxene and andesitic rocks with minor amounts of hornblende, epidote, calcite, magnetite and chlorite ; siltstone fragments are locally abundant. North-west of Canomodine, brown-coloured hornblende is more prominent, biotite is occasionally present and there is a greater variety of basic lava fragments. The siltstones in the formation have a similar mineralogical composition to the arenites.

Overlying the Canomodine Limestones on the eastern side are about 250 feet of siltstones with a few poorly-preserved diplograptid graptolites, followed by 1000 feet of massive arenite with only faint traces of bedding. The upper part of the formation consists of about 2,800 feet of siltstones and arenites which show graded bedding. Slump structures are well developed and a remarkable clastic dyke of arenite penetrates the siltstones on the river bank near "Millambri".

Upstream, a fault cuts off the eastern extension of the formation, but south of "Cranky Rock", the top of the formation is marked by a lenticular bed of andesitic agglomerate, and in the central part of Portion 2, Parish of Chaucer, by limestone with *Favosites* sp. and stromatoporoids.

The formation disappears due to faulting at Canomodine and reappears two miles to the north-east on the opposite side of a belt of Silurian sediments. From here it has been traced beyond the Cargo Road, where siliceous siltstones with graded bedding and clastic veins overlie more massive arenites or tuffs. North-west of the Cargo Road, these beds thin out or are overlapped by Silurian buff and reddish shales.

The andesitic tuffs which outcrop around the southern end of the andesite belt of Barragan and those which overlie the same andesites north of Oaky Creek may belong to the Millambri Formation.

Fossils found in the formation so far indicate either an Upper Ordovician or a Lower Silurian age ; better-preserved fossils have been found in rocks associated with the formation, but of doubtful stratigraphical position. For example, at "The Glen" (between Cargo Road and Canomodine) graptolites from weathered shale between two outcrops of Canomodine Limestone are suggestive of Lower Silurian types. Definite Upper Ordovician graptolites have been found in shales at the south-east end of the Cargo Creek Limestone between the limestone and the Cargo Andesite, but the area is heavily faulted.

Geological map of the Cargo District, showing Ordovician formations.
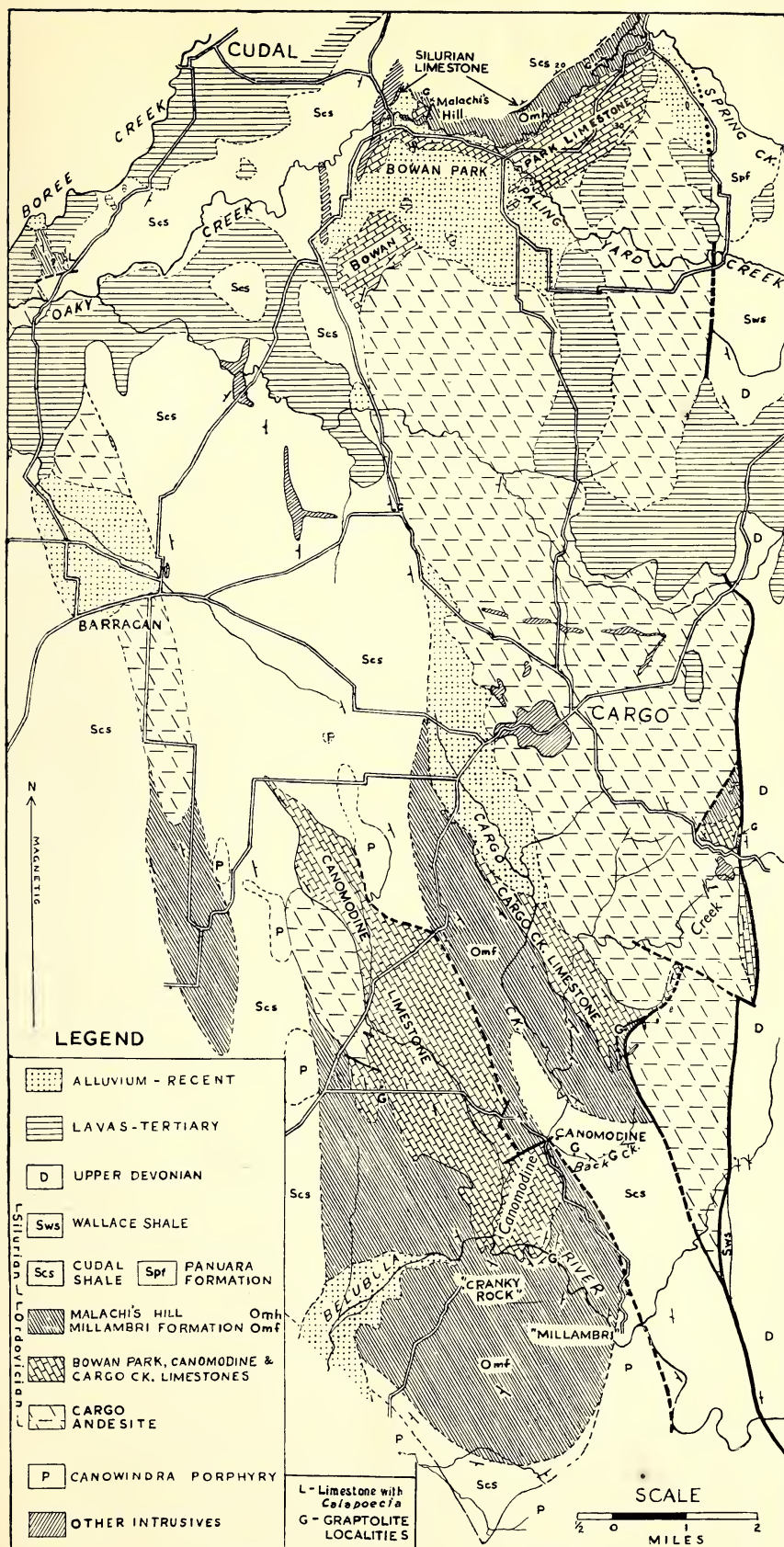
(2) Malachi's Hill Formation.

It is proposed to use this name for the formation of siltstone, shale, tuff and andesite which overlies the Barton and Bowan Park Limestones and underlies Silurian limestones and shales in the Bowan Park District. The Ordovician rocks which overlie the Barton Limestone in the faulted area between Spring, Quarry and Oaky Creeks (Packham and Stevens, 1955) are tentatively assigned to this formation.

The base of the formation is exposed on the south-west slopes of Malachi's Hill, where impure limestones at the top of the Bowan Park Limestone pass upwards into calcareous siltstones with dendroid and climacograptid grapolites. These beds may be followed east up Oaky Creek, where they are intercalated with coarse andesitic tuff. Further north-east, andesites, tuffs and brown shales appear in addition to the banded siltstones. The following section is exposed on the western side of Oaky Creek, all except the upper three members in a cliff section :

	feet.
9. Lower (?) Silurian limestone	
8. Andesite	100
7. Tuff	} 200
6. Black siltstone	
5. Andesite and tuff	180
4. Brown shales and mudstones with *Climacograptus inuiti*	
3. Tuff	} 180
2. Black siltstones with poorly-preserved graptolites ..	
1. Bowan Park Limestone	

The andesites, tuffs, etc. which outcrop between Silurian beds in Spring and Quarry Creeks (eastern outcrop—Packham and Stevens, 1955) may be correlated with the higher andesite in this section, while the andesites overlain by shale with *Climacgraptus supernus*, *C*. cf. *inuiti* and *Orthograptus* sp. near the junction of Spring and Oaky Creeks (western outcrop) is probably the same horizon as the lower andesite and tuffs of the cliff section.

IV. Ordovician Sediments East of Cliefden Caves.

Felspathic siltstones and arenites of different lithology to, but of the same age (zones of *Glyptograptus teretiusculus* and *Nemagraptus gracilis*) as the Malongulli Formation are developed in a broad arc east, north and south-east of Cliefden Caves. They have been folded with the overlying Angullong Tuff into an anticline with smaller marginal synclines (text-fig. 1).

These siltstones and arenites will be placed in the Malongulli Formation, and to distinguish them from the calcareous siltstones, spiculites etc. of Cliefden Caves, the former will be termed the siltstone-arenite facies while the latter will be termed the calcareous facies of the formation.

The coarser sediments are either interbedded with the siltstones in regular beds several millimetres thick or form massive beds several feet thick. Some exhibit graded bedding, and in certain areas (e.g. Merrimalong and Swallow Creeks) slipbedding and slump structures are common in the finer sediments, which have been broken into discontinuous irregular fragments surrounded by arenite. Andesite, unfossiliferous limestone and intraformational conglomerate are found in thin beds, making a minor part of the formation.

The coarser sediments commonly contain fragments of plagioclase (albite or andesine), ferromagnesian minerals, andesitic lavas and black siltstone

Quartz, chalcedony, calcite, chlorite, epidote, magnetite and pyrite may also occur. The degree of sorting is variable but generally poor and the clayey or chloritic matrix ranges from 5 to 35%.

On the eastern side of the major fold the oldest representatives of the siltstone-arenite facies are the black laminated siltstones which overlie andesites in the gorge of Mandurama Ponds Creek east of The Junction Reefs. The andesitic formation might be tentatively correlated with the Middle Ordovician Walli Andesite. Graptolites from the lowest siltstone beds are poorly preserved *Glyptograptus teretiusculus,* and further down the creek, loose blocks have yielded
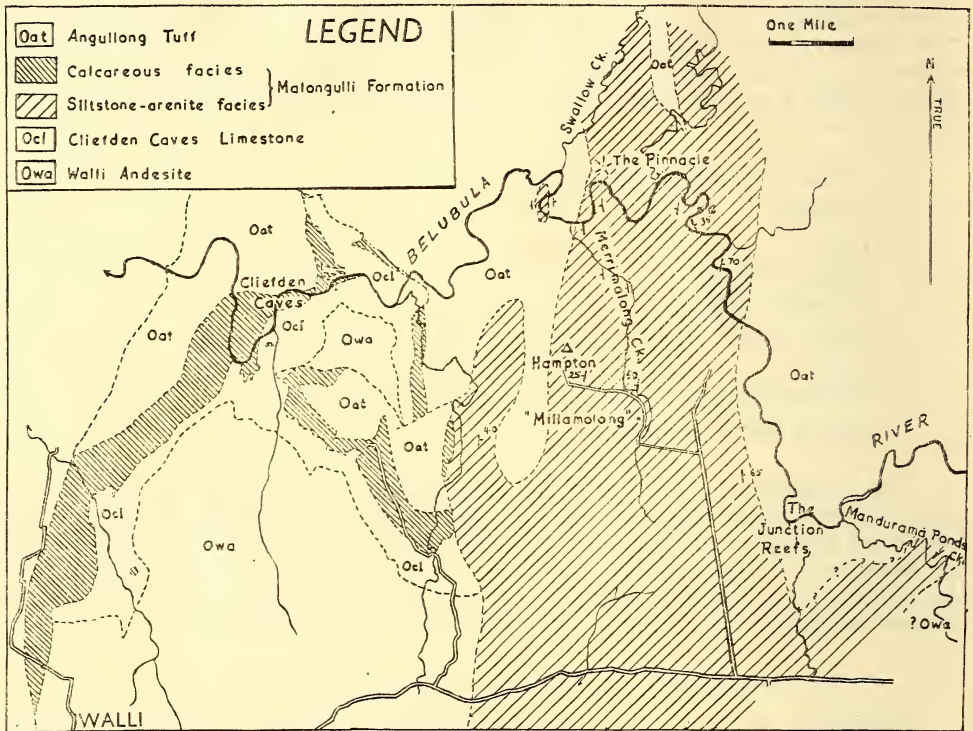
Text-fig. 1.—Distribution of the two facies of the Malongulli Formation in the Belubula River Valley. (Post-Ordovician and intrusive rocks omitted.)

better specimens, associated with brachiopods (? *Obolella*) and Asaphid trilobites (Pittman, 1900). The graptolites, described by Hall (1900) as *Diplograptus manduramæ* and *Climacograptus affinis*, have both been regarded as *G. teretiusculus* by Sherrard (1954).

The oldest beds in the core of the major anticline north of " Millamolong " are regularly bedded siltstones with black, fine-grained and lighter, coarser-grained laminæ, often with graded bedding. A thin bed of conglomerate outcropping at C (text-fig. 1) has sub-angular and closely packed fragments of bluish grey, well-bedded siltstone. In this area, too, some thin beds of unfossiliferous limestone appear east of the fold axis.

Graptolites are present in some of the more calcareous siltstones, but as a rule, they are not well preserved. *Isograptus* cf. *caduceus* and *Amplexograptus* sp., found near the basalt cap of The Pinnacle, are an exception and suggest a rather low zone, possibly that of *G. teretiusculus*. Traces of graptolites and

large *Lingula*-like brachiopods occur in weathered siltstones on the road to
" Millamolong ", close to the anticlinal axis.

Higher in the sequence, black siltstones are interbedded with redistributed
andesitic tuffs. Thin and irregularly distributed grey limestones are interbedded
with siltstones and arenites near The Pinnacle, and above this horizon are dark
calcareous siltstones in which graptolites of Llandeilo age have been found
(Stevens, 1954). These beds have been traced along the boundary with the
Angullong Tuff past Hampton Trig., two miles south of which, *G. teretiusculus*,
Orthograptus pagianus var. *abnormispinus* and *Dicellograptus sextans* var. *exilis*
have been found. At the top of the formation, crystal tuffs begin to appear ;
these rocks have idiomorphic albite crystals and lack the usual rock fragments
of the siltstone-arenite facies.

A small inlier on the Belubula River south of the junction with Swallow
Creek shows a gradation from siltstone-arenite to calcareous facies, as fine
and coarse arenites are interbedded with black, siliceous limestone, calcareous
siltstone and limestone breccia.

V. PALÆOGEOGRAPHY.

From a consideration of this and earlier papers on the Cargo and Cliefden
Caves districts some general statements on the Ordovician palæogeography
of this area may now be made.

In Middle Ordovician times, this part of New South Wales was situated in
the middle of the Tasman geosyncline, remote from any large land mass. The
oldest rocks now exposed are Middle Ordovician volcanics, which, by their pillow
structure and albitization, suggest submarine deposition. In the Cliefden Caves
area they are conformably overlain by fossilferous limestones of shallow water
origin, so at least the uppermost lavas and tuffs were deposited in shallow water.
Accumulation of volcanic material built up a submarine ridge which may have
been raised partly by tectonic forces, this being the first sign of the median
geanticline which was a notable feature after the Benambran epi-Ordovician
Orogeny (Browne, 1947).

The lithology of the Cliefden Caves Limestone, varying from thinly bedded
limestones with large brachiopods at the base, followed by beds with reef-building
corals and later, small brachiopods, to massive limestones with rhythmically
arranged chert bands, indicates slow subsidence at a rate which exceeded
deposition, so that younger sediments were deposited in increasingly deeper
water.

The calcareous facies of the Malongulli Formation is, in places, interbedded
with massive limestones, and presumably was deposited in water of moderate
depth, the graptolites indicating that deeper water was not far away. Terrigenous
detritus is practically absent from these rocks, but the siltstone-arenite facies
of the Malongulli Formation and the lithologically similar Millambri Formation
consist of material derived from an andesitic land mass and show sedimentary
structures characteristic of the greywacke suite (Packham, 1954), of relatively
deep water deposition. Graded-bedded sediments of similar mineralogical
composition and texture from the Aure Trough, Papua, have been described
as greywackes (Edwards, 1950), and the formation of sediments with similar
sedimentary structures in the Upper Ordovician of Victoria has been ascribed
to turbidity currents (Hills and Thomas, 1954).

The siltstone-arenite facies is equivalent to, but thicker than the calcareous
facies, and as deeper water conditions are more likely in the former it is assumed
that more rapid subsidence took place east of Cliefden Caves, forming a deep
trough. The greywacke suite sediments were not derived from the western side
(where the calcareous facies is developed), but may have come from the east

or north-east. The non-appearance of the Cliefden Caves Limestone above the andesites on the east side of the trough may be attributed to deeper water or to lack of clarity in the water due to transport of muddy sediments across this area into the trough.

Some of the clastic sediments may have been deposited as a direct result of explosive volcanism, but because of the thickness of the deposits, their uniformity within the trough, their lithology and sedimentary structures, it is considered that true tuffs are in the minority.

At Bowan Park, and possibly in the Canomodine district, the formation of massive limestone continued into Upper Ordovician times (Table 1), and was followed by eruption of andesitic lavas, tuffs and breccias. In periods of quiescence, fine-grained sediments were deposited and conditions were suitable for the growth and preservation of graptolites.

VI. Acknowledgments.

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CONVERSIONS BETWEEN EQUATORIAL COORDINATES AND STANDARD COORDINATES ON PHOTOGRAPHIC PLATES.

By Harley Wood.

ABSTRACT.
A method is described of converting equatorial coordinates to standard rectangular coordinates and vice versa.   The necessary tables are given.

The standard coordinates X, Y of a star of right ascension α and declination δ on a photographic plate having centre A, D are given by the equations

$$\tan q = \tan \delta \sec (\alpha - A), \quad \dots\dots\dots\dots\dots\dots\dots \quad (1)$$

$$Y = f \tan (q - D), \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

$$X = \tan (\alpha - A)\{f \cos D - Y \sin D\}, \quad \dots\dots\dots\dots \quad (3)$$

where q is auxiliary and f is the focal length of the camera in the units in which the standard coordinates are required.

In working to a given accuracy with formulæ (2) and (3) it is necessary to use more significant figures in (1).   This, however, may be written

$$\tan (q - \delta) = \frac{\{\sec (\alpha - A) - 1\} \tan \delta}{1 + \tan^2 \delta \sec (\alpha - A)},$$

which gives

$$q - \delta = \sin 2\delta \left\{ \frac{1}{4}(\alpha - A)^2 + \frac{1}{24}(\alpha - A)^4 + \frac{1}{16}(\alpha - A)^4 \cos 2\delta + \dots \right\}.$$

If we choose to calculate $(q - \delta)$ in minutes of arc and write, with $(\alpha - A)$ in minutes of time,

$$L = 1 \cdot 63624617 \times 10^{-2}(\alpha - A)^2 + 5 \cdot 1919697 \times 10^{-8}(\alpha - A)^4,$$

$$M = 7 \cdot 7879546 \times 10^{-8}(\alpha - A)^4,$$

then

$$(q - \delta)' = \sin 2\delta(L + M \cos 2\delta) + N. \quad \dots\dots\dots\dots \quad (4)$$

L and M are given in Table I with argument $(\alpha - A)$ and N, which in many practical cases is negligible, is given in units of the fourth decimal place in Table II with arguments $(\alpha - A)$ and δ.   The tables were calculated to two more places than the tabulation.   The note at the foot of Table I is to allow for second differences in the tabulated values of L.

Table III is a table of Y with argument $(q - D)'$ at interval $1'$, but since it is different for different instruments and easily formed by multiplying the entries of a table of tangents by the appropriate value of f it is not given here.   At Sydney, with a micrometer measuring in millimetres, we have two such tables

HARLEY WOOD.

TABLE I.

α—A m s	L $'$	M $'$		α—A m s.	L $'$	M $'$
0 0	$0\cdot0000\ _5$	$0\cdot0000_0$		8 0	$1\cdot0474_{441}$	$0\cdot0003_0$
10	$0\cdot0005\ _{13}$	$0\cdot0000_0$		10	$1\cdot0915_{450}$	$0\cdot0003_1$
20	$0\cdot0018\ _{23}$	$0\cdot0000_0$		20	$1\cdot1365_{460}$	$0\cdot0004_0$
30	$0\cdot0041\ _{32}$	$0\cdot0000_0$		30	$1\cdot1825_{468}$	$0\cdot0004_0$
40	$0\cdot0073\ _{41}$	$0\cdot0000_0$		40	$1\cdot2293_{477}$	$0\cdot0004_1$
0 50	$0\cdot0114\ _{50}$	$0\cdot0000_0$		8 50	$1\cdot2770_{487}$	$0\cdot0005_0$
1 0	$0\cdot0164\ _{59}$	$0\cdot0000_0$		9 0	$1\cdot3257_{496}$	$0\cdot0005_1$
10	$0\cdot0223\ _{68}$	$0\cdot0000_0$		10	$1\cdot3753_{504}$	$0\cdot0006_0$
20	$0\cdot0291\ _{77}$	$0\cdot0000_0$		20	$1\cdot4257_{514}$	$0\cdot0006_0$
30	$0\cdot0368\ _{87}$	$0\cdot0000_0$		30	$1\cdot4771_{523}$	$0\cdot0006_1$
40	$0\cdot0455\ _{95}$	$0\cdot0000_0$		40	$1\cdot5294_{532}$	$0\cdot0007_0$
1 50	$0\cdot0550_{105}$	$0\cdot0000_0$		9 50	$1\cdot5826_{542}$	$0\cdot0007_1$
2 0	$0\cdot0655_{113}$	$0\cdot0000_0$		10 0	$1\cdot6368_{550}$	$0\cdot0008_0$
10	$0\cdot0768_{123}$	$0\cdot0000_0$		10	$1\cdot6918_{559}$	$0\cdot0008_1$
20	$0\cdot0891_{132}$	$0\cdot0000_0$		20	$1\cdot7477_{569}$	$0\cdot0009_0$
30	$0\cdot1023_{141}$	$0\cdot0000_0$		30	$1\cdot8046_{578}$	$0\cdot0009_1$
40	$0\cdot1164_{150}$	$0\cdot0000_0$		40	$1\cdot8624_{586}$	$0\cdot0010_1$
2 50	$0\cdot1314_{159}$	$0\cdot0000_0$		10 50	$1\cdot9210_{596}$	$0\cdot0011_0$
3 0	$0\cdot1473_{168}$	$0\cdot0000_0$		11 0	$1\cdot9806_{605}$	$0\cdot0011_1$
10	$0\cdot1641_{177}$	$0\cdot0000_0$		10	$2\cdot0411_{614}$	$0\cdot0012_1$
20	$0\cdot1818_{186}$	$0\cdot0000_0$		20	$2\cdot1025_{623}$	$0\cdot0013_1$
30	$0\cdot2004_{196}$	$0\cdot0000_0$		30	$2\cdot1648_{633}$	$0\cdot0014_0$
40	$0\cdot2200_{204}$	$0\cdot0000_0$		40	$2\cdot2281_{641}$	$0\cdot0014_1$
3 50	$0\cdot2404_{214}$	$0\cdot0000_0$		11 50	$2\cdot2922_{651}$	$0\cdot0015_1$
4 0	$0\cdot2618_{223}$	$0\cdot0000_0$		12 0	$2\cdot3573_{659}$	$0\cdot0016_1$
10	$0\cdot2841_{232}$	$0\cdot0000_0$		10	$2\cdot4232_{669}$	$0\cdot0017_1$
20	$0\cdot3073_{241}$	$0\cdot0000_0$		20	$2\cdot4901_{678}$	$0\cdot0018_1$
30	$0\cdot3314_{250}$	$0\cdot0000_0$		30	$2\cdot5579_{687}$	$0\cdot0019_1$
40	$0\cdot3564_{259}$	$0\cdot0000_0$		40	$2\cdot6266_{696}$	$0\cdot0020_1$
4 50	$0\cdot3823_{268}$	$0\cdot0000_0$		12 50	$2\cdot6962_{705}$	$0\cdot0021_1$
5 0	$0\cdot4091_{277}$	$0\cdot0000_0$		13 0	$2\cdot7667_{715}$	$0\cdot0022_1$
10	$0\cdot4368_{287}$	$0\cdot0001_0$		10	$2\cdot8382_{723}$	$0\cdot0023_2$
20	$0\cdot4655_{295}$	$0\cdot0001_0$		20	$2\cdot9105_{733}$	$0\cdot0025_1$
30	$0\cdot4950_{305}$	$0\cdot0001_0$		30	$2\cdot9838_{742}$	$0\cdot0026_1$
40	$0\cdot5255_{313}$	$0\cdot0001_0$		40	$3\cdot0580_{750}$	$0\cdot0027_2$
5 50	$0\cdot5568_{323}$	$0\cdot0001_0$		13 50	$3\cdot1330_{760}$	$0\cdot0029_1$
6 0	$0\cdot5891_{332}$	$0\cdot0001_0$		14 0	$3\cdot2090_{769}$	$0\cdot0030_1$
10	$0\cdot6223_{341}$	$0\cdot0001_0$		10	$3\cdot2859_{779}$	$0\cdot0031_2$
20	$0\cdot6564_{350}$	$0\cdot0001_0$		20	$3\cdot3638_{787}$	$0\cdot0033_1$
30	$0\cdot6914_{359}$	$0\cdot0001_1$		30	$3\cdot4425_{797}$	$0\cdot0034_2$
40	$0\cdot7273_{368}$	$0\cdot0002_0$		40	$3\cdot5222_{805}$	$0\cdot0036_2$
6 50	$0\cdot7641_{378}$	$0\cdot0002_0$		14 50	$3\cdot6027_{815}$	$0\cdot0038_1$
7 0	$0\cdot8019_{386}$	$0\cdot0002_0$		15 0	$3\cdot6842_{824}$	$0\cdot0039_2$
10	$0\cdot8405_{396}$	$0\cdot0002_0$		10	$3\cdot7666_{833}$	$0\cdot0041_2$
20	$0\cdot8801_{405}$	$0\cdot0002_0$		20	$3\cdot8499_{842}$	$0\cdot0043_2$
30	$0\cdot9206_{413}$	$0\cdot0002_1$		30	$3\cdot9341_{851}$	$0\cdot0045_2$
40	$0\cdot9619_{423}$	$0\cdot0003_0$		40	$4\cdot0192_{860}$	$0\cdot0047_2$
7 50	$1\cdot0042_{432}$	$0\cdot0003_0$		15 50	$4\cdot1052_{870}$	$0\cdot0049_2$
8 0	$1\cdot0474$	$0\cdot0003$		16 0	$4\cdot1922$	$0\cdot0051$

If the fraction of the interval between two tabular values is
between $0\cdot13$ and $0\cdot87$ subtract $0'\cdot0001$ from L

TABLE I.

α—A (m s)	L (′)	M (′)	α—A (m s)	L (′)	M (′)
16 0	$4 \cdot 1922_{879}$	$0 \cdot 0051_{2}$	24 0	$9 \cdot 4420_{1318}$	$0 \cdot 0258_{8}$
10	$4 \cdot 2801_{887}$	$0 \cdot 0053_{2}$	10	$9 \cdot 5738_{1328}$	$0 \cdot 0266_{7}$
20	$4 \cdot 3688_{897}$	$0 \cdot 0055_{3}$	20	$9 \cdot 7066_{1337}$	$0 \cdot 0273_{8}$
30	$4 \cdot 4585_{906}$	$0 \cdot 0058_{2}$	30	$9 \cdot 8403_{1346}$	$0 \cdot 0281_{7}$
40	$4 \cdot 5491_{916}$	$0 \cdot 0060_{3}$	40	$9 \cdot 9749_{1355}$	$0 \cdot 0288_{8}$
16 50	$4 \cdot 6407_{924}$	$0 \cdot 0063_{2}$	24 50	$10 \cdot 1104_{1364}$	$0 \cdot 0296_{8}$
17 0	$4 \cdot 7331_{933}$	$0 \cdot 0065_{3}$	25 0	$10 \cdot 2468_{1374}$	$0 \cdot 0304_{8}$
10	$4 \cdot 8264_{943}$	$0 \cdot 0068_{2}$	10	$10 \cdot 3842_{1382}$	$0 \cdot 0312_{9}$
20	$4 \cdot 9207_{952}$	$0 \cdot 0070_{3}$	20	$10 \cdot 5224_{1392}$	$0 \cdot 0321_{8}$
30	$5 \cdot 0159_{961}$	$0 \cdot 0073_{3}$	30	$10 \cdot 6616_{1402}$	$0 \cdot 0329_{9}$
40	$5 \cdot 1120_{970}$	$0 \cdot 0076_{3}$	40	$10 \cdot 8018_{1410}$	$0 \cdot 0338_{9}$
17 50	$5 \cdot 2090_{979}$	$0 \cdot 0079_{3}$	25 50	$10 \cdot 9428_{1420}$	$0 \cdot 0347_{9}$
18 0	$5 \cdot 3069_{988}$	$0 \cdot 0082_{3}$	26 0	$11 \cdot 0848_{1428}$	$0 \cdot 0356_{9}$
10	$5 \cdot 4057_{998}$	$0 \cdot 0085_{3}$	10	$11 \cdot 2276_{1438}$	$0 \cdot 0365_{9}$
20	$5 \cdot 5055_{1006}$	$0 \cdot 0088_{3}$	20	$11 \cdot 3714_{1447}$	$0 \cdot 0374_{10}$
30	$5 \cdot 6061_{1016}$	$0 \cdot 0091_{4}$	30	$11 \cdot 5161_{1457}$	$0 \cdot 0384_{10}$
40	$5 \cdot 7077_{1025}$	$0 \cdot 0095_{3}$	40	$11 \cdot 6618_{1465}$	$0 \cdot 0394_{10}$
18 50	$5 \cdot 8102_{1034}$	$0 \cdot 0098_{3}$	26 50	$11 \cdot 8083_{1475}$	$0 \cdot 0404_{10}$
19 0	$5 \cdot 9136_{1043}$	$0 \cdot 0101_{4}$	27 0	$11 \cdot 9558_{1484}$	$0 \cdot 0414_{10}$
10	$6 \cdot 0179_{1053}$	$0 \cdot 0105_{4}$	10	$12 \cdot 1042_{1494}$	$0 \cdot 0424_{11}$
20	$6 \cdot 1232_{1061}$	$0 \cdot 0109_{4}$	20	$12 \cdot 2536_{1502}$	$0 \cdot 0435_{10}$
30	$6 \cdot 2293_{1071}$	$0 \cdot 0113_{4}$	30	$12 \cdot 4038_{1512}$	$0 \cdot 0445_{11}$
40	$6 \cdot 3364_{1080}$	$0 \cdot 0117_{4}$	40	$12 \cdot 5550_{1521}$	$0 \cdot 0456_{11}$
19 50	$6 \cdot 4444_{1089}$	$0 \cdot 0121_{4}$	27 50	$12 \cdot 7071_{1530}$	$0 \cdot 0467_{12}$
20 0	$6 \cdot 5533_{1098}$	$0 \cdot 0125_{4}$	28 0	$12 \cdot 8601_{1539}$	$0 \cdot 0479_{11}$
10	$6 \cdot 6631_{1107}$	$0 \cdot 0129_{4}$	10	$13 \cdot 0140_{1549}$	$0 \cdot 0490_{12}$
20	$6 \cdot 7738_{1117}$	$0 \cdot 0133_{5}$	20	$13 \cdot 1689_{1558}$	$0 \cdot 0502_{12}$
30	$6 \cdot 8855_{1126}$	$0 \cdot 0138_{4}$	30	$13 \cdot 3247_{1567}$	$0 \cdot 0514_{12}$
40	$6 \cdot 9981_{1134}$	$0 \cdot 0142_{5}$	40	$13 \cdot 4814_{1576}$	$0 \cdot 0526_{12}$
20 50	$7 \cdot 1115_{1144}$	$0 \cdot 0147_{4}$	28 50	$13 \cdot 6390_{1586}$	$0 \cdot 0538_{13}$
21 0	$7 \cdot 2259_{1154}$	$0 \cdot 0151_{5}$	29 0	$13 \cdot 7976_{1594}$	$0 \cdot 0551_{13}$
10	$7 \cdot 3413_{1162}$	$0 \cdot 0156_{5}$	10	$13 \cdot 9570_{1604}$	$0 \cdot 0564_{13}$
20	$7 \cdot 4575_{1171}$	$0 \cdot 0161_{5}$	20	$14 \cdot 1174_{1614}$	$0 \cdot 0577_{13}$
30	$7 \cdot 5746_{1181}$	$0 \cdot 0166_{6}$	30	$14 \cdot 2788_{1622}$	$0 \cdot 0590_{13}$
40	$7 \cdot 6927_{1190}$	$0 \cdot 0172_{5}$	40	$14 \cdot 4410_{1632}$	$0 \cdot 0603_{14}$
21 50	$7 \cdot 8117_{1199}$	$0 \cdot 0177_{5}$	29 50	$14 \cdot 6042_{1641}$	$0 \cdot 0617_{14}$
22 0	$7 \cdot 9316_{1208}$	$0 \cdot 0182_{6}$	30 0	$14 \cdot 7683_{1650}$	$0 \cdot 0631_{14}$
10	$8 \cdot 0524_{1217}$	$0 \cdot 0188_{6}$	10	$14 \cdot 9333_{1659}$	$0 \cdot 0645_{14}$
20	$8 \cdot 1741_{1227}$	$0 \cdot 0194_{6}$	20	$15 \cdot 0992_{1669}$	$0 \cdot 0659_{15}$
30	$8 \cdot 2968_{1236}$	$0 \cdot 0200_{6}$	30	$15 \cdot 2661_{1678}$	$0 \cdot 0674_{15}$
40	$8 \cdot 4204_{1245}$	$0 \cdot 0206_{6}$	40	$15 \cdot 4339_{1687}$	$0 \cdot 0689_{15}$
22 50	$8 \cdot 5449_{1254}$	$0 \cdot 0212_{6}$	30 50	$15 \cdot 6026_{1697}$	$0 \cdot 0704_{15}$
23 0	$8 \cdot 6703_{1263}$	$0 \cdot 0218_{6}$	31 0	$15 \cdot 7723_{1705}$	$0 \cdot 0719_{16}$
10	$8 \cdot 7966_{1272}$	$0 \cdot 0224_{7}$	10	$15 \cdot 9428_{1715}$	$0 \cdot 0735_{16}$
20	$8 \cdot 9238_{1282}$	$0 \cdot 0231_{7}$	20	$16 \cdot 1143_{1725}$	$0 \cdot 0751_{16}$
30	$9 \cdot 0520_{1291}$	$0 \cdot 0238_{6}$	30	$16 \cdot 2868_{1733}$	$0 \cdot 0767_{16}$
40	$9 \cdot 1811_{1300}$	$0 \cdot 0244_{7}$	40	$16 \cdot 4601_{1743}$	$0 \cdot 0783_{17}$
23 50	$9 \cdot 3111_{1309}$	$0 \cdot 0251_{7}$	31 50	$16 \cdot 6344_{1752}$	$0 \cdot 0800_{17}$
24 0	$9 \cdot 4420$	$0 \cdot 0258$	32 0	$16 \cdot 8096$	$0 \cdot 0817$

If the fraction of the interval between two tabular values is
between $0 \cdot 13$ and $0 \cdot 87$ subtract $0' \cdot 0001$ from L

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TABLE I.

α—A m s	L ′	M ′	α—A m s	L ′	M ′
32 0	$16 \cdot 8096_{1761}$	$0 \cdot 0817_{17}$	36 0	$21 \cdot 2930_{1984}$	$0 \cdot 1308_{24}$
10	$16 \cdot 9857_{1771}$	$0 \cdot 0834_{17}$	10	$21 \cdot 4914_{1993}$	$0 \cdot 1332_{25}$
20	$17 \cdot 1628_{1780}$	$0 \cdot 0851_{18}$	20	$21 \cdot 6907_{2003}$	$0 \cdot 1357_{25}$
30	$17 \cdot 3408_{1789}$	$0 \cdot 0869_{18}$	30	$21 \cdot 8910_{2013}$	$0 \cdot 1382_{26}$
40	$17 \cdot 5197_{1798}$	$0 \cdot 0887_{18}$	40	$22 \cdot 0923_{2021}$	$0 \cdot 1408_{25}$
32 50	$17 \cdot 6995_{1808}$	$0 \cdot 0905_{19}$	36 50	$22 \cdot 2944_{2031}$	$0 \cdot 1433_{27}$
33 0	$17 \cdot 8803_{1817}$	$0 \cdot 0924_{18}$	37 0	$22 \cdot 4975_{2040}$	$0 \cdot 1460_{26}$
10	$18 \cdot 0620_{1826}$	$0 \cdot 0942_{19}$	10	$22 \cdot 7015_{2050}$	$0 \cdot 1486_{27}$
20	$18 \cdot 2446_{1836}$	$0 \cdot 0961_{20}$	20	$22 \cdot 9065_{2059}$	$0 \cdot 1513_{27}$
30	$18 \cdot 4282_{1844}$	$0 \cdot 0981_{20}$	30	$23 \cdot 1124_{2068}$	$0 \cdot 1540_{28}$
40	$18 \cdot 6126_{1855}$	$0 \cdot 1001_{19}$	40	$23 \cdot 3192_{2078}$	$0 \cdot 1568_{28}$
33 50	$18 \cdot 7981_{1863}$	$0 \cdot 1020_{21}$	37 50	$23 \cdot 5270_{2087}$	$0 \cdot 1596_{28}$
34 0	$18 \cdot 9844_{1873}$	$0 \cdot 1041_{20}$	38 0	$23 \cdot 7357_{2096}$	$0 \cdot 1624_{29}$
10	$19 \cdot 1717_{1881}$	$0 \cdot 1061_{21}$	10	$23 \cdot 9453_{2105}$	$0 \cdot 1653_{29}$
20	$19 \cdot 3598_{1892}$	$0 \cdot 1082_{21}$	20	$24 \cdot 1558_{2115}$	$0 \cdot 1682_{29}$
30	$19 \cdot 5490_{1900}$	$0 \cdot 1103_{22}$	30	$24 \cdot 3673_{2125}$	$0 \cdot 1711_{30}$
40	$19 \cdot 7390_{1910}$	$0 \cdot 1125_{22}$	40	$24 \cdot 5798_{2133}$	$0 \cdot 1741_{30}$
34 50	$19 \cdot 9300_{1919}$	$0 \cdot 1147_{22}$	38 50	$24 \cdot 7931_{2143}$	$0 \cdot 1771_{31}$
35 0	$20 \cdot 1219_{1929}$	$0 \cdot 1169_{22}$	39 0	$25 \cdot 0074_{2152}$	$0 \cdot 1802_{31}$
10	$20 \cdot 3148_{1937}$	$0 \cdot 1191_{23}$	10	$25 \cdot 2226_{2162}$	$0 \cdot 1833_{31}$
20	$20 \cdot 5085_{1948}$	$0 \cdot 1214_{23}$	20	$25 \cdot 4388_{2171}$	$0 \cdot 1864_{32}$
30	$20 \cdot 7033_{1956}$	$0 \cdot 1237_{23}$	30	$25 \cdot 6559_{2181}$	$0 \cdot 1896_{32}$
40	$20 \cdot 8989_{1966}$	$0 \cdot 1260_{24}$	40	$25 \cdot 8740_{2189}$	$0 \cdot 1928_{33}$
35 50	$21 \cdot 0955_{1975}$	$0 \cdot 1284_{24}$	39 50	$26 \cdot 0929_{2200}$	$0 \cdot 1961_{33}$
36 0	$21 \cdot 2930$	$0 \cdot 1308$	40 0	$26 \cdot 3129$	$0 \cdot 1994$

If the fraction of the interval between two tabular values is between $0 \cdot 13$ and $0 \cdot 87$ subtract $0' \cdot 0001$ from L

TABLE II.   N (Unit $0' \cdot 0001$).

α—A δ°	22m	24m	26m	28m	30m	32m	34m	36m	38m	40m	°
0	0	0	0	0	0	0	0	0	0	0	90
5	0	0	+1	+1	+1	+2	+3	+ 4	+ 5	+ 7	85
10	0	+1	+1	+2	+2	+3	+5	+ 7	+10	+13	80
15	0	+1	+1	+2	+3	+4	+6	+ 9	+12	+17	75
20	0	+1	+1	+2	+3	+5	+7	+10	+13	+18	70
25	0	+1	+1	+2	+3	+4	+6	+ 9	+13	+17	65
30	0	+1	+1	+2	+2	+4	+5	+ 7	+10	+14	60
35	0	0	+1	+1	+2	+2	+4	+ 5	+ 7	+ 9	55
40	0	0	0	+1	+1	+1	+2	+ 2	+ 3	+ 5	50
45	0	0	0	0	0	0	0	0	0	+ 1	45
50	0	0	0	0	0	−1	−1	− 1	− 2	− 2	40
55	0	0	0	0	−1	−1	−1	− 2	− 3	− 4	35
60	0	0	0	0	−1	−1	−1	− 2	− 3	− 4	30
65	0	0	0	0	−1	−1	−1	− 2	− 2	− 3	25
70	0	0	0	0	0	0	−1	− 1	− 1	− 2	20
75	0	0	0	0	0	0	0	0	− 1	− 1	15
80	0	0	0	0	0	0	0	0	0	0	10
85	0	0	0	0	0	0	0	0	0	0	5
90	0	0	0	0	0	0	0	0	0	0	0
	22m	24m	26m	28m	30m	32m	34m	36m	38m	40m	q α—A

N = 0 if α—A < 22m

TABLE IV. Q (Unit $0' \cdot 0001$).

$\alpha - A$ / δ or q	6^m	7^m	8^m	9^m	10^m	11^m	12^m	13^m	14^m	15^m	16^m	17^m	18^m	19^m	20^m	$\alpha - A$ / δ or q
0 45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45 90
1 44	0	0	0	0	0	0	1	1	1	1	2	2	3	4	4	46 89
2 43	0	0	0	0	1	1	1	2	2	3	4	5	6	7	9	47 88
3 42	0	0	0	1	1	1	2	2	3	4	5	7	8	11	13	48 87
4 41	0	0	0	1	1	2	2	3	4	5	7	9	11	14	17	49 86
5 40	0	0	1	1	1	2	3	4	5	7	9	11	14	17	21	50 85
6 39	0	0	1	1	2	2	3	5	6	8	10	13	17	21	25	51 84
7 38	0	0	1	1	2	3	4	5	7	9	12	15	19	24	29	52 83
8 37	0	0	1	1	2	3	4	6	8	10	14	17	22	27	33	53 82
9 36	0	1	1	2	2	3	5	7	9	12	15	19	24	30	37	54 81
10 35	0	1	1	2	3	4	5	7	10	13	16	21	26	33	40	55 80
11 34	0	1	1	2	3	4	6	8	10	14	18	23	28	35	43	56 79
12 33	0	1	1	2	3	4	6	8	11	15	19	24	30	38	46	57 78
13 32	0	1	1	2	3	4	6	9	12	16	20	26	32	40	49	58 77
14 31	0	1	1	2	3	5	7	9	12	16	21	27	34	42	52	59 76
15 30	0	1	1	2	3	5	7	10	13	17	22	28	35	44	54	60 75
16 29	0	1	1	2	4	5	7	10	13	18	23	29	37	46	56	61 74
17 28	0	1	1	2	4	5	7	10	14	18	24	30	38	47	58	62 73
18 27	0	1	2	2	4	5	8	11	14	19	24	31	39	48	59	63 72
19 26	0	1	2	2	4	6	8	11	15	19	25	32	40	49	60	64 71
20 25	0	1	2	3	4	6	8	11	15	19	25	32	40	50	61	65 70
21 24	0	1	2	3	4	6	8	11	15	20	25	32	41	50	62	66 69
22 23	0	1	2	3	4	6	8	11	15	20	26	32	41	51	62	67 68

Q **has the same sign as left-hand arguments but the opposite sign to arguments on the right**

corresponding to $f = 3438$ mm. (standard astrograph) and $f = 2063$ mm. (for the camera which belongs to Yale University Observatory).

The standard coordinates may be computed using equation (4) with Tables I and II, equation (2) with Table III and equation (3).

Suppose as an example we take $(\alpha - A) = 35^m\ 16^s \cdot 213$, $\delta = 64° 46' 32'' \cdot 88$ and $D = 61°$ and the unit of measurement on the plate corresponding to $100''$ (i.e. $f = 2062 \cdot 6481$) then we have

2δ	$129° 33' 5'' \cdot 76$		$\delta - D$	$+226' \cdot 5480$
$\sin 2\delta$	$0 \cdot 771051$		$q - \delta$	$+ 15' \cdot 6971$
$\cos 2\delta$	$-0 \cdot 6368$		$q - D$	$+242' \cdot 2451$
$\tan (\alpha - A)$	$0 \cdot 1551219$		Y	$+145 \cdot 5881$
L	$20 \cdot 4350$		X	$135 \cdot 3683$
M	$0 \cdot 1205$			

If we wish to compute right ascension and declination from the standard coordinates (1) may be written

$$\tan (q - \delta) = \frac{\{\sec (\alpha - A) - 1\} \cot q}{1 + \cot^2 q \sec (\alpha - A)},$$

which shows that the value of $(q - \delta)$ corresponding to $q = r$ is the same as that corresponding to $\delta = 90 - r$ and hence

$$(q - \delta)' = \sin 2q (L - M \cos 2q) + N \quad \dots\dots\dots\dots (5)$$

where N is obtained from Table II with arguments $(\alpha - A)$ and q, the latter of which is entered on the right-hand side of the table.

F

The computation is then done by calculating $(\alpha - A)$ from equation (3), $(q - D)$ from Table III and δ from equation (5) using Tables I and II. As an example of calculating equatorial coordinates, take D, X and Y of the previous example. Then formula (3) gives $(\alpha - A)$, L and M the same values as before, after which (2) (Table III) and (5) give

$q-D$	$4°\ 2'\ 14''\cdot70$	$\cos 2q$	$-0\cdot6438$
q	$65°\ 2'\ 14''\cdot70$	$q-\delta$	$15'\cdot6971$
$2q$	$130°\ 4'\ 29''\cdot40$	δ	$64°\ 46'\ 32''\cdot88$
$\sin 2q$	$0\cdot765204$		

These tables may easily be modified to suit circumstances or the taste of the computer. If $\alpha - A$ cannot exceed 20 minutes equation (4) may be written

$$(q-\delta)'=L \sin 2\delta+\{M \cos 2\delta \sin 2\delta+N\},$$

where the part in the curly bracket $(=Q)$ can be tabulated with arguments $\alpha - A$ and δ or q. For the inverse calculation, where q must be the argument,

$$(q-\delta)'=L \sin 2q-Q.$$

Q is given in Table IV. It has the same sign as the argument if entered through values on the left-hand side of the table and the opposite sign for values on the right.

If $\alpha - A$ does not exceed 10 minutes and an accuracy of $0'\cdot001$ is satisfactory then $(q-\delta)'=L \sin 2\delta$ would serve.

MINOR PLANETS OBSERVED AT SYDNEY OBSERVATORY DURING 1955.

By W. H. ROBERTSON.

The following observations of minor planets were made photographically at Sydney Observatory with the 13″ standard astrograph and the 8″ Yale camera. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0′·5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were recorded on a chronograph with a tapping key.

TABLE I.

1955 U.T.	Planet.	R.A. (1950·0)	Dec. (1950·0)	Parallax Factors.
		h m s	° ′ ″	s ″
231 Mar. 28·61730	84 Klio	13 04 33·06	—18 44 18·4	+0·02 —2·3
232 Apr. 14·55672	84 Klio	12 46 58·22	—17 45 11·4	+0·02 —2·4
233 Apr. 26·59544	89 Julia	14 32 06·03	—40 46 40·2	+0·01 +1·1
234 May 18·52189	89 Julia	14 08 00·02	—39 05 55·7	+0·03 +0·8
235 May 31·67957	115 Thyra	17 58 48·53	—36 41 44·1	+0·15 +0·3
236 July 4·51694	115 Thyra	17 19 34·00	—34 57 48·3	—0·01 +0·2
237 Sep. 1·53054	186 Celuta	21 09 27·86	—36 34 11·2	+0·08 +0·4
238 May 4·70117	264 Libussa	16 54 14·85	—26 36 01·4	+0·11 —1·2
239 June 22·54632	264 Libussa	16 10 21·72	—27 23 57·3	+0·14 —1·1
240 July 4·55596	270 Anahita	17 47 38·49	—21 47 37·3	+0·06 —1·8
241 July 4·65607	283 Emma	20 24 10·39	—21 26 27·6	+0·03 —1·9
242 Aug. 8·53306	283 Emma	19 54 18·16	—21 14 55·8	+0·01 —1·9
243 July 26·56210	292 Ludovica	19 37 15·64	—45 24 30·9	+0·03 +1·8
244 Aug. 8·50121	292 Ludovica	19 23 56·73	—45 19 37·4	—0·04 +1·8
245 Mar. 28·65957	310 Margarita	14 04 04·89	—15 00 09·6	+0·02 —2·8
246 Apr. 20·59163	310 Margarita	13 47 24·03	—13 03 14·8	+0·05 —3·1
247 Aug. 18·57417	351 Yrsa	21 20 08·20	—24 24 26·3	+0·04 —1·4
248 Sep. 7·48573	351 Yrsa	21 05 21·15	—25 37 27·2	+0·04 —1·3
249 Apr. 20·62920	390 Alma	14 21 13·74	—34 40 05·6	+0·11 +0·1
250 May 3·59243	390 Alma	14 08 07·94	—33 46 18·7	+0·13 —0·1
251 Apr. 4·57399	409 Aspasia	12 33 22·57	—18 17 08·0	+0·04 —2·3
252 Apr. 18·51210	409 Aspasia	12 13 07·28	—16 04 04·5	—0·02 —2·7
253 July 6·55642	426 Hippo	18 10 35·40	—40 58 28·2	+0·03 +1·1
254 July 25·49554	426 Hippo	17 53 47·93	—38 40 13·1	+0·04 +0·8
255 Aug. 18·54029	447 Valentine	21 11 31·26	—23 08 18·7	+0·08 —1·7
256 Aug. 25·52794	447 Valentine	21 06 07·58	—23 30 12·6	—0·02 —1·6
257 May 19·58027	450 Brigitta	15 42 11·58	—30 25 34·3	+0·01 —0·5
258 June 1·51760	450 Brigitta	15 30 08·79	—30 08 19·2	—0·06 —0·6
259 Aug. 4·56178	464 Megaira	19 57 42·39	—26 40 48·8	+0·06 —1·1
260 Aug. 18·48620	464 Megaira	19 47 38·50	—27 56 09·2	—0·05 —0·9
261 May 3·63594	514 Armida	16 18 47·43	—24 14 16·1	—0·04 —1·5
262 May 18·60304	514 Armida	16 07 25·98	—23 37 06·7	+0·02 —1·5
263 May 31·55333	514 Armida	15 56 35·08	—22 55 12·9	—0·01 —1·7
264 May 4·70117	528 Rezia	16 49 54·29	—27 01 14·8	+0·12 —1·1

TABLE I.—*Continued*.

1955 U.T.		Planet.	R.A. (1950·0)	Dec. (1950·0)	Parallax Factors.
			h m s	° ′ ″	s ″
265	June 22·54632	528 Rezia	16 11 16·44	—28 00 29·6	+0·14 —1·0
266	May 4·61342	541 Deborah	14 23 15·40	—21 33 10·0	+0·16 —2·0
267	May 16·51924	541 Deborah	14 13 49·15	—20 21 48·6	—0·02 —2·0
268	May 19·62565	567 Eleutheria	16 36 37·73	—23 58 16·9	+0·04 —1·5
269	May 31·59296	567 Eleutheria	16 26 01·47	—24 12 02·5	+0·06 —1·6
270	June 22·50822	567 Eleutheria	16 08 05·64	—24 24 32·2	+0·02 —1·4
271	Mar. 31·53114	576 Emanuela	11 22 53·87	— 9 24 45·8	0·00 —3·6
272	Apr. 14·46040	576 Emanuela	11 14 02·32	— 8 20 21·2	—0·08 —3·8
273	Nov. 3·55610	582 Olympia	1 35 15·84	—29 03 58·6	+0·09 —0·8
274	Apr. 21·56914	657 Gunlod	12 50 06·18	—24 35 59·3	+0·11 —1·5
275	June 1·65532	702 Alauda	17 44 16·36	—38 09 57·6	+0·11 +0·6
276	June 28·52094	702 Alauda	17 18 10·06	—35 46 44·3	—0·05 +0·3
277	June 23·60948	717 Wisibada	18 45 04·73	—25 34 54·1	0·00 —1·2
278	July 25·52928	717 Wisibada	18 17 40·95	—25 44 08·8	+0·09 —1·3
279	Oct. 5·51070	729 Watsonia	22 56 13·51	—25 46 07·6	+0·04 —1·2
280	May 19·66978	734 Benda	17 35 34·94	—30 58 42·0	+0·05 —0·4
281	May 31·63435	734 Benda	17 26 28·25	—31 08 44·7	+0·02 —0·4
282	June 23·56034	734 Benda	17 06 24·70	—30 57 30·5	+0·07 —0·5
283	Sep. 27·51079	786 Bredichina	22 19 30·15	—29 54 18·7	+0·06 —0·6
284	Aug. 4·53312	834 Burnhamia	20 00 07·55	—14 48 22·3	—0·04 —2·9
285	July 7·58248	845 Naëma	18 47 56·44	—39 46 39·6	+0·04 +0·9
286	July 29·51961	845 Naëma	18 27 44·76	—40 04 02·6	+0·08 +0·9
287	July 4·68626	930 Westphalia	21 11 39·30	—37 11 01·0	+0·02 +0·5
288	Aug. 17·54564	930 Westphalia	20 21 04·32	—34 13 46·1	+0·08 0·0
289	Aug. 9·55146	932 Hooveria	20 41 30·17	—31 03 38·7	—0·03 —0·4
290	Aug. 26·51010	932 Hooveria	20 25 20·31	—30 55 59·9	+0·02 —0·5
291	Apr. 26·63159	979 Ilsewa	15 22 48·85	—19 34 12·1	+0·01 —2·1
292	May 16·56126	979 Ilsewa	15 07 54·77	—17 46 41·3	—0·01 —2·4
293	May 30·51664	979 Ilsewa	14 57 52·32	—16 28 53·0	0·00 —2·6
294	May 18·56076	983 Gunila	15 12 37·17	—24 59 32·1	0·00 —1·3
295	May 31·51108	983 Gunila	15 03 21·30	—23 13 28·1	—0·02 —1·6
296	Mar. 28·61730	1001 Gaussia	13 00 27·09	—18 49 06·8	+0·03 —2·3
297	Apr. 14·55672	1001 Gaussia	12 48 19·17	—17 24 50·1	+0·01 —2·5
298	Apr. 18·55264	1001 Gaussia	12 45 35·65	—17 01 54·2	+0·04 —2·5
299	May 30·63028	1002 Olbersia	16 40 08·23	—39 25 40·9	+0·16 +0·7
300	June 23·51377	1002 Olbersia	16 15 25·48	—38 20 43·9	—0·03 +0·7
301	Apr. 20·68143	1005 Arago	15 07 10·66	—40 37 22·0	+0·20 +0·7
302	May 19·53310	1005 Arago	14 39 04·74	—40 26 42·6	0·00 +1·0
303	Mar. 24·58700	1031 Arctica	11 48 12·05	—16 07 16·4	+0·06 —2·7
304	Apr. 14·50365	1031 Arctica	11 35 56·89	—12 33 47·7	0·00 —3·2
305	July 26·53474	1034 Mozartia	18 38 39·38	—25 04 46·1	+0·07 —1·3
306	Aug. 5·48330	1034 Mozartia	18 34 29·57	—24 19 49·1	0·00 —1·4
307	Mar. 23·66428	1241 Dysona	13 14 47·76	—39 11 44·6	+0·13 +0·7
308	Mar. 31·61850	1241 Dysona	13 07 19·02	—39 37 32·4	+0·06 +0·9
309	May 3·49946	1241 Dysona	12 35 18·02	—38 31 24·8	+0·03 +0·7
310	May 18·64198	1242 Zambesia	17 15 56·20	—37 33 10·3	—0·01 +0·6
311	June 27·54391	1242 Zambesia	16 35 34·74	—36 55 53·3	+0·14 +0·4
312	Mar. 23·60422	1277 Dolores	12 32 10·87	—13 45 27·6	+0·01 —3·0
313	Apr. 20·53863	1277 Dolores	12 09 20·18	—10 33 02·2	+0·09 —3·5
314	June 1·56743	1319 Disa	16 01 42·76	—21 36 54·0	+0·04 —1·8
315	June 15·54591	1319 Disa	15 51 51·59	—20 47 43·1	+0·12 —2·0
316	May 31·67957	1366 Piccolo	17 59 05·44	—36 19 49·3	+0·15 +0·3
317	July 6·51622	1366 Piccolo	17 24 08·03	—37 21 51·6	0·00 +0·6
318	June 27·67606	1374 Isora	20 18 56·90	—22 23 01·4	+0·04 —1·7
319	Aug. 10·53024	1374 Isora	19 36 54·56	—20 55 01·8	+0·05 —2·0
320	Aug. 18·54029	1378 Leonce	21 08 05·07	—23 11 16·7	—0·05 —1·6
321	Aug. 25·56614	1955QS₁	21 39 00·78	—23 45 05·8	+0·03 —1·5
322	Sep. 7·51865	1955RJ₁	21 32 19·05	—24 47 19·5	0·00 —1·4

TABLE II.

Comparison Stars.	Dependences.			
231 Yale *12* II 5620, 5622, 5632	0·18821	0·09393	0·71786	R
232 Yale *12* I 4891, 4904, 4908	0·42437	0·29617	0·27946	W
233 Cord. D 9778, 9791, 9843	0·09954	0·47659	0·42387	R
234 Cord. D 9462, 9488, 9527	0·30391	0·39333	0·30276	R
235 Cape Annals *18* 9165, 9173, 9195	0·36662	0·03848	0·59489	W
236 Cape Annals *17* 9159, 9188, *18* 8672	0·17038	0·33694	0·49268	S
237 Cape Annals *18* 10933, 10949, 10952	0·44840	0·36742	0·18418	R
238 Yale *14* 11694, 11721, 11727	0·23708	0·55964	0·20328	W
239 Yale *14* 11373, *13* II 10179, 10199	0·41073	0·53304	0·05623	W
240 Yale *13* I 7298, 7329, *14* 12247	0·50867	0·24200	0·24933	S
241 Yale *14* 14166, *13* I 8764, 8790	0·41910	0·33871	0·24219	S
242 Yale *13* I 8538, 8547, 8568	0·48936	0·22642	0·28421	S
243 Cord. D 14378, 14414, 14426	0·27031	0·31359	0·41610	S
244 Cape Ft. 18644, 18651, 18691	0·48557	0·03491	0·47952	S
245 Yale *12* I 5276, 5289, *11* 4986	0·79131	—0·02778	0·23647	R
246 Yale *11* 4893, 4903, 4909	0·13018	0·81784	0·05198	S
247 Yale *14* 14710, 14735, 14767	0·35252	0·38661	0·26087	R
248 Yale *14* 14574, 14612, 14616	0·33627	0·44648	0·21725	R
249 Cape Annals *17* 7373, 7402, 7407	0·48472	0·11026	0·40503	S
250 Cape Annals *17* 7232, 7257, 7262	0·27672	0·36130	0·36198	W
251 Yale *12* I 4770, 4774, *12* II 5401	0·41089	0·33426	0·25486	S
252 Yale *12* I 4723, 4733, 4737	0·30892	0·41676	0·27432	S
253 Cord. D 13268, 13285, 13313	0·23113	0·18551	0·58336	S
254 Cord. D 13002, 13046, 13057	0·29161	0·42211	0·28628	S
255 Yale *14* 14641, 14665, 14669	0·19627	0·39270	0·41103	R
256 Yale *14* 14590, 14604, 14630	0·25290	0·44196	0·30514	R
257 Cape Annals *17* 8137, 8139, 8162	0·19916	0·39679	0·40405	R
258 Yale *13* II 9716, 9731, 9738	0·27717	0·30822	0·41461	W
259 Yale *14* 13912, 13952, *13* II 13137	0·43552	0·37545	0·18903	R
260 Yale *13* II 12995, 13021, 13030	0·18468	0·24567	0·56965	R
261 Yale *14* 11433, 11437, 11454	0·09677	0·28892	0·61432	W
262 Yale *14* 11333, 11340, 11372	0·22180	0·24647	0·53173	R
263 Yale *14* 11238, 11247, 11249	0·30197	0·12462	0·57341	W
264 Yale *14* 11661, 11694, *13* II 10589	0·38031	0·24560	0·37409	W
265 Yale *13* II 10168, 10179, 10194	0·37742	0·24365	0·37893	W
266 Yale *13* I 6013, 6025, 6032	0·22880	0·12561	0·64560	W
267 Yale *12* II 5964, 5976, *13* I 5977	0·26692	0·59431	0·13877	R
268 Yale *14* 11544, 11557, 11559	0·52825	0·25374	0·21801	R
269 Yale *14* 11470, 11475, 11504	0·29904	0·11895	0·58201	W
270 Yale *14* 11333, 11358, 11382	0·28535	0·38182	0·33282	W
271 Yale *16* 4282, 4286, 4289	0·58827	0·02932	0·38241	R
272 Yale *16* 4230, 4247, 4250	0·27995	0·42330	0·29675	R
273 Yale *13* II 562, 576, 586	0·15657	0·18702	0·65641	R
274 Yale *14* 9611, 9617, 9635	0·44215	0·30770	0·25015	S
275 Cord. D 12862, 12866, 12909	0·32460	0·62957	0·04583	W
276 Cape Annals *18* 8656, 8663, 8668	0·25129	0·47469	0·27402	R
277 Yale *14* 13038, 13041, 13067	0·16065	0·46538	0·37397	W
278 Yale *14* 12677, 12690, 12710	0·23376	0·32330	0·44294	S
279 Yale *14* 15449, 15462, 15479	0·15524	0·54059	0·30417	R
280 Cape Annals *17* 9332, 9353, 9364	0·31100	0·53345	0·15555	R
281 Cape Annals *17* 9236, 9240, 9283	0·43592	0·33548	0·22860	W
282 Cape Annals *17* 9013, 9022, 9036	0·33093	0·33555	0·33352	W
283 Cape Annals *17* 12143, 12147, 12153	0·19691	0·33477	0·46832	S
284 Yale *12* I 7519, 7530, 7533	0·28962	0·47267	0·23771	R
285 Cord. D 13828, 13862, 13882	0·32481	0·46050	0·21469	S
286 Cord. D 13501, 13560, 13576	0·24683	0·31571	0·43746	S
287 Cord. D 15253, 15291, 15293	0·15963	0·53314	0·30723	S
288 Cape Annals *17* 11108, 11116, 11134	0·40076	0·27604	0·32320	R
289 Cape Annals *17* 11300, 11323, 11339	0·37959	0·35859	0·26182	S
290 Cape Annals *17* 11150, 11160, 11175	0·20407	0·29194	0·50399	S
291 Yale *12* II 6369, 6371, 6389	0·56002	0·07661	0·36337	R

TABLE II.—*Continued.*

Comparison Stars.	Dependences.			
292 Yale *12* I 5579, 5580, 5594	0·19749	0·33417	0·46834	R
293 Yale *12* I 5528, 5538, 5539	0·31244	0·53146	0·15610	W
294 Yale *14* 10853, 10868, 10892	0·35869	0·37063	0·27068	R
295 Yale *14* 10783, 10787, 10801	0·17316	0·33196	0·49488	W
296 Yale *12* II 5602, 5620, *12* I 4966	0·38823	0·23977	0·37199	R
297 Yale *12* I 4891, 4908, 4917	0·26809	0·21115	0·52077	W
298 Yale *12* I 4892, 4893, 4899	0·66560	0·22988	0·10452	S
299 Cord. D 11662, 11665, 11731	0·40949	0·29115	0·29936	W
300 Cord. D 11340, 11355, 11381	0·32921	0·31999	0·35080	W
301 Cord. D 10348, 10349, 10404	0·33443	0·32296	0·34261	S
302 Cord. D 9912, 9916, 9932	0·15754	0·47484	0·36762	R
303 Yale *12* I 4610, 4627, 4631	0·32788	0·24841	0·42371	W
304 Yale *11* 4320, 4331, 4335	0·29108	0·49160	0·21732	W
305 Yale *14* 12957, 12981, 12984	0·39089	0·09940	0·50971	S
306 Yale *14* 12905, 12919, 12947	0·29953	0·32643	0·37404	S
307 Perth *,2* 885, *6* 1123, 1126	0·18658	0·55192	0·26150	W
308 Cord. D 8655, 8690, 8691	0·29855	0·31049	0·39096	R
309 Cord. D 8257, 8267, 8286	0·35000	0·04588	0·60412	W
310 Cord. D 12298, 12337, 12382	0·26676	0·33552	0·39772	R
311 Cape Annals *18* 8210, 8226, 8238	0·20842	0·45255	0·33903	R
312 Yale *11* 4541, 4555, 4571	0·35384	0·25658	0·38958	W
313 Yale *11* 4458, 4462, *16* 4507	0·59875	0·24494	0·15630	S
314 Yale *13* I 6628, 6631, 6648	0·59791	0·15540	0·24669	W
315 Yale *13* I 6555, 6570, 6585	0·20967	0·35946	0·43087	S
316 Cape Annals *18* 9173, 9195, 9205	0·51126	0·23349	0·25525	W
317 Cord. D 12460, 12468, 12525	0·46325	0·15838	0·37837	S
318 Yale *14* 14132, 14134, 14146	0·37483	0·45814	0·16703	R
319 Yale *13* I 8407, 8424, 8428	0·17510	0·53199	0·29291	R
320 Yale *14* 14604, 14638, 14641	0·31399	0·40241	0·28360	R
321 Yale *14* 14874, 14878, 14904	0·38672	0·23367	0·37961	R
322 Yale *14* 14825, 14838, 14847	0·54817	0·15889	0·29294	R

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial coordinates was used. Proper motions, when they were available, were applied to bring the star positions to the epoch of the plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time except in cases 251, 281, 291, 307, 311, 312, where each result is from only one image, due to a defect in the other exposure or a failure in timing it. No correction has been applied for aberration, light time or parallax but in Table I are given the factors which give the parallax correction when divided by the distance. The serial numbers follow on from those of a previous paper (Robertson, 1955). The observers named in Table II are W. H. Robertson (R), K. P. Sims (S), and H. W. Wood (W). Miss P. Lawler and Mrs. M. Wilson assisted in the measurement of the plates and in part of the computation.

REFERENCE.

Robertson, W. H., 1955. THIS JOURNAL, **89**, 85.

THE STRATIGRAPHY AND PETROLOGY OF THE NARRABEEN GROUP IN THE GROSE RIVER DISTRICT.

KEITH A. W. CROOK.

(University of New England.)

ABSTRACT.

The Narrabeen Group in the Grose River district is divided into: the Caley Formation (sandstone and shale), succeeded by the Grose Sandstone, succeeded by the Burralow Formation (sandstone, shale and " chocolate shale "). Petrographic descriptions indicate a source containing low-grade metamorphics and abundant quartz veins.   Notes on the Permian are included.

CONTENTS.

INTRODUCTION.

The scope of this paper is, in the main, a study of the Narrabeen Group in the valley of the Grose River and its tributaries in the western portion of the Windsor One Mile Military Sheet and the central-eastern portion of the Katoomba Sheet (see Text-fig. 5). Also some notes on the Permian in this district have been included.

The area, lying some 45 miles north-west of Sydney, is in the heart of the Permo-Triassic Cumberland Basin. It consists dominantly of Triassic rocks, with Permian appearing beneath them in the west, and is capped in spots by Tertiary volcanics and Pleistocene lacustrine beds.   The Permo-Triassic sequence is generally horizontal or shallowly dipping, but steep dips appear in the Kurrajong Heights-Burralow Creek district associated with the Lapstone Monocline and Kurrajong Fault.

The specimen numbers used throughout refer to specimens and slides housed in the museum at the Department of Geology and Geophysics, University of Sydney.   This work formed a portion of a thesis submitted for the degree of Master of Science in March, 1956.

STRATIGRAPHY AND SEDIMENTARY PETROGRAPHY.

The general sequence of rocks in the area may be summarized as follows :

? Middle Triassic ..   Hawkesbury Sandstone.
? Lower Triassic   ..   Narrabeen Group :

> Burralow Formation : Shales and sandstones exposed mainly in the valleys of the Grose and Colo Rivers and their tributaries. The Formation includes the Tabarag Sandstone Member.
> Grose Sandstone : Massive sandstones exposed as the preceding.
> Caley Formation : Shales and sandstones exposed in the Upper Grose Valley.

Permian   ..   ..   Lithgow Coal Measures : Bituminous coals, carbonaceous shales, siltstones and vitric tuffs, exposed in the Upper Grose Valley.

Permian.—Descending to the valley floor from Govett's Leap, the Permian is first met with near the foot of the Bridal Veil Falls, where a six-feet coal seam (probably the Katoomba Seam) is developed. A sequence measured at the foot of the Falls shows :

Carbonaceous silty claystone	..	..	Above.	
Coal, bituminous	..	..	..	1½ ft.
Vitric tuff, banded ..	..	..	..	10 ft.
Coal, bituminous	..	..	..	6 ft.

Further down the valley, on the course of Govett's Leap Creek, pebbly mudstones and shales, probably of marine origin, occur. These are well developed at the junction of this creek with Rodriguez Pass Creek, where igneous pebbles are frequent.

Passing down the Grose River from Bluegum Forest, the Permian makes poor outcrops until the high sandstone cliffs above it come close to the river. Here, on the south bank at 431482 Katoomba, excellent cliff-sections of the upper portions of the Lithgow Coal Measures, with the Narrabeen Group above, are developed. At the foot of the cliffs about two feet of good quality bituminous coal are exposed. This is overlain by a rhythmically bedded sequence of shales and silty sandstones with lenses and bands of vitric tuff. The shales, some of which are properly cherty claystones, are richly fossiliferous, specimens of *Glossopteris* sp. and *Alethopteris* sp. being recognizable amongst the macerated plant debris (Specimen KC. GR110/54).

The type of sedimentation exhibited by this sequence is, as far as the author is aware, unique in the Permo-Triassic basin. The thin but persistent nature of the beds, the rhythmic alternation of two rock types, the presence of micro-cross-stratification in the coarser layers, and the existence of frequent slump structures all suggest deposition from turbidity currents in deep water (*vide* Packham, 1954, p. 467). This, however, conflicts with present ideas on deposition in the Permian coal basin, viz. lacustrine and fluviatile.

There seems little doubt that the sequence is the result of turbidity current deposition, but it remains to be shown that all cases of such deposition occur in deep water. It seems possible that, under certain conditions of deposition in coal swamps, turbidity currents may develop and the material they deposit may be preserved. While the mechanism for such occurrences may be obscure, this view seems preferable to one involving deep water deposition of this portion of the Coal Measures.

About a quarter of a mile downstream (434486), again on the south bank, good exposures of vitric tuff and shale occur. The tuff contains plant debris, and certain bedding surfaces are pitted and roughened due to the incorporation of this material. Included patches of quartz-rich detritus have been noted.

Slightly east of this point the Permian, dipping at about 15° to the south-east, disappears beneath the floor of the valley. The actual junction between the Lithgow coal Measures and the overlying Caley formation is not exposed due to talus cover.

Petrography of Lithgow Coal Measures Rocks.—The tuffs (GR2, GR111) are in general fine dense hard rocks, cherty in appearance, and well bedded. They vary from grey to white and show many microvesicles, and are similar to those from Nobby's Head near Newcastle.

Thin sections show a well developed vitro-clastic texture, although shards are not visible in the very fine types. The coarser types, however, show shards and may develop an almost mylonitic appearance, due presumably to some flowage and rearrangement of the ash on deposition.

Certain coarse types show close resemblances to the ignimbrites described by Oliver (1954) from the Borrowdale Volcanic Series of the English Lakes District. The development of a rough flow structure and the large crystal fragments included are the most obviously similar features.

In general, clastic detritus is restricted to occasional quartz grains. The major constituent is a colourless devitrified glass, alteration of which has given rise to patches of quartz and chloritic material. Some true chlorite, which is brown or colourless and has a 2V(+) large and birefringence <0·005, is present. This may be detrital. In the very fine grained tuffs small rounded composite patches of quartz occur which are strongly suggestive of radiolaria.

In the cliff section, which shows evidences of turbidity current deposition, the tuffs are partly replaced by carbonate. In outcrop they show good bedding and slump structures. A slight vitreous lustre betrays the presence of the carbonate.

Thin sections reveal a patchy replacement of the shards by ankerite. The unaltered patches show the original devitrified glass and chloritic material. In plane polarized light the vitro-clastic texture is readily visible due to the strong absorption of the ankerite. Some detritus is present, chiefly quartz, together with muscovite, chlorite and a little weathered iron ore.

The siltstones associated with this tuff (GR109) are very fine, even grained, hard and finely bedded with an even fracture. Micro-cross-stratification is frequent. In thin section much of the material is an irresolvable chlorite-clay mineral complex. Small amounts of detrital quartz and muscovite are present, together with carbonaceous material. It is probable that the irresolvable material is devitrified glass.

Triassic. (a) *Narrabeen Group.* Wilkinson, 1887. (*Vide* Hanlon *et al.*, 1952.)

In the Colo-Grose District, as in many other parts, the Narrabeen Group is differentiated from the overlying Hawkesbury Sandstone by an abrupt change in lithology from shale to quartz-rich sandstone.

It has been found convenient to subdivide the Narrabeen Group in this area in a manner different from that employed elsewhere in the basin (see above). The traditional marker beds, the " chocolate shales " (henceforth referred to as " red-brown claystones "), occur in up to three separate beds whose positions in the column are somewhat variable. A more workable subdivision can be obtained on the basis of prominent sandstone units. These are readily visible in the field, and stand out well in aerial photographs.

FIG. 1. CORRELATION OF TRIASSIC STRATIGRAPHIC COLUMNS.
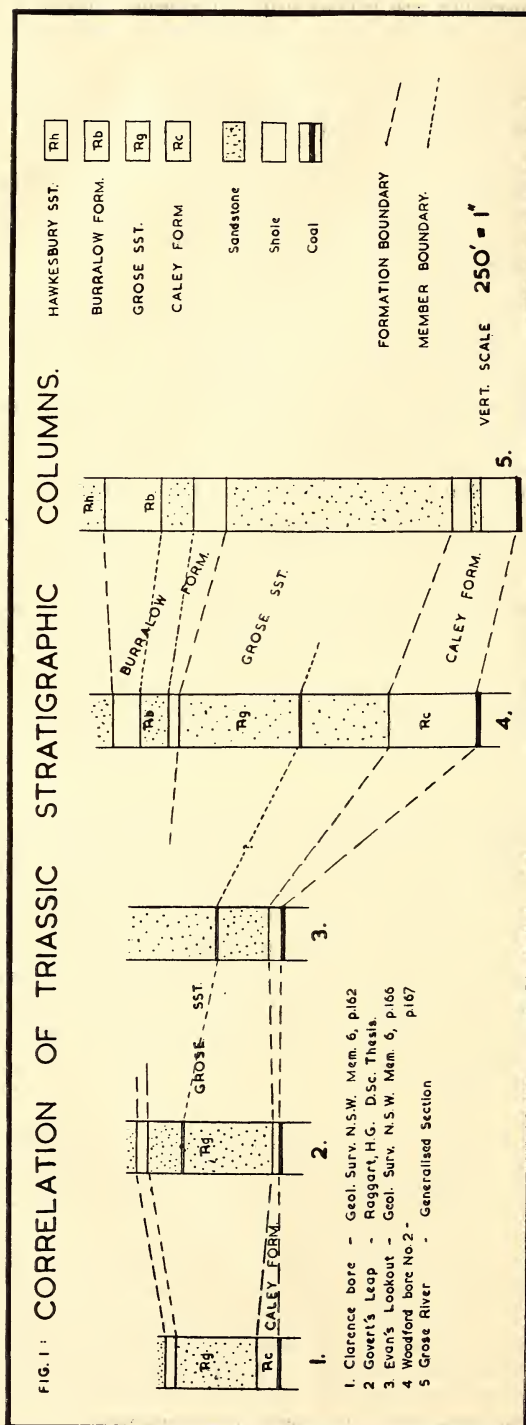
Text-fig. 1.

Caley Formation (nov.).—Named from Mt. Caley, on the north bank of the Grose River.   The Formation outcrops along the Grose at the foot of the cliffs in this region.

Thickness :   About 150 feet.

Type Section (provisional) :   Section No. 1 at 439(.5)487(.5) Katoomba. This section is partial.   (See Text-fig. 3.)

Due to talus cover it has not been possible to examine a complete section of the Caley Formation.   It is, however, delimited upwards by the base of the massive Grose Sandstone, and downwards by the top of the topmost (Katoomba) coal seam.

The sequence of 60 ft. of " cherts, sandstone and shale " measured by Carne (1908, p. 179) give the basal portion of the Formation.   It seems likely that the " sandstone cliffs " referred to in his description represent the 30 ft. sandstone in the Caley Formation, rather than the base of the Grose Sandstone.

The Formation is of widespread occurrence, being thinnest in the west. Good outcrops occur immediately overlying the coal on the track from Govett's Leap to Bluegum Forest.   Shales are dominant in this region, and are accompanied by an unusual type of chloritic silty mudstone.

In the Clarence Bore (Carne, 1908, p. 162) the Caley Formation is thinner, the section being :

Soft chert and shale	11 ft.
Chert and sandstone	34 ft.
Conglomerate and ironstone bands ..	3 ft.
Sandstone and conglomerate	18 ft.
	66 ft.

The chert referred to is probably the chloritic silty mudstone.

In the Woodford Bore No. 2 (Carne, 1908, p. 167) it seems that the 270 ft. of strata above the coal may represent the Caley formation.   The bore-log is, unfortunately, insufficiently detailed to enable accurate determination.

Petrography of Caley Formation Rocks.—Petrographically the rocks of this Formation are similar to those of the Burralow Formation above (*q.v.*).   The sandstones are sub-labile and contain quartz of plutonic igneous or vein origin and minor amounts of argillite fragments.   They have been insufficiently examined to enable determination of their range of variation.

The chloritic silty mudstone already referred to is grey, hard, massive and unbedded, with a slightly waxy lustre and numerous " micro-vesicles ".   The most prominent constituent is very finely comminuted chlorite.   Small amounts of coarser fragments of chlorite, together with minor muscovite and sericite, are present.   Silt-size quartz grains, some with undulose extinction, and a little zircon, yellow tourmaline and iron ore also occur.

Grose Sandstone (nov.).   Named from the Grose River, along which the Formation outcrops, forming bold cliffs.

Thickness :   About 700 ft.

Provisional Type Section :   Two partial sections, No. 1 at 439(.5)487(.5) Katoomba and No. 7 at 605462 Windsor.

No complete section of the Grose Sandstone has yet been measured.   Such sections do occur upstream from the point of outcrop of the Caley Formation in the Grose Valley, but the area is difficult of access, and high vertical cliffs have so far prevented attempts to obtain a complete section.

The Formation, as observed in the lower Grose Valley, is without marker beds. In view of the existence of a red-brown claystone within the Formation at Govett's Leap, Woodford, and doubtfully at Evan's Lookout, it seems possible that it may be present in the Grose River area. If so, it has passed unobserved, which is not surprising in view of the thickness of the Formation and the terrain.

As can be seen from Text-figure 1, the Formation thins appreciably to the west. To the south, at Woodford, it has maintained its thickness, whilst to the north-west it is almost certainly thickening.

In general the massive sandstones persist throughout the Formation, but in some places they become flaggy and interbeds of shale and siltstone occur. The lower part of the Formation at Govett's Leap is noticeably more shaley than the upper, and along Burralow Creek some $1\frac{1}{2}$ miles south of Tabarag Ridge fissile flaggy sandstones and shales are developed. At 623468 Windsor, on Burralow Creek, nodules of sideritic mudstone are found in the walls of a cave produced by the erosion of a shale lens.

Further upstream at 604492(.5) Windsor there is a good development of small mud balls in the sandstone. These are ellipsoidal with dimensions up to 25 mm. × 15 mm., major and minor axes. The two minor axes are often approximately equal. The balls are composed of a very pale brown clay.

Several types of cross-stratification occur within the Grose Sandstone. The most common type is planar cross-stratification (*vide* McKee and Weir, 1953). Both tabular and wedge-shaped planar sets are found, the former being by far the most common. Internally the cross-strata are either straight, straight with a slight flexure at the base, or gently curved, concave upwards. Some trough cross-stratification is present, the cross-strata always being curved, concave upwards. Graded cross-stratification occurs in some places, as for example at several points in Wheeny Gap (627517 St. Albans).

The thickness of the planar sets varies from 2 in. to 6 ft., those less than 6 in. being associated with other sets to form a co-set 2 ft. or more thick. The most frequent thickness would be in the range $1\frac{1}{2}$ to 3 ft. The trough sets are generally under 1 ft. thick.

Red siltstone is known from within the Grose Sandstone at 439(.5)487(.5) Katoomba. Although similar in colour to the red-brown claystones of the Narrabeen Group, it differs from them in its coarser texture and incipient bedding, which is a fine uneven lamination, and in the widespread occurrence of detrital muscovite.

The sandstones vary widely in texture and composition. Fine to medium grained types predominate. The composition varies from labile to sub-labile ; no specimens describable as quartzose sandstones have been encountered. There is a significant difference in composition between these sandstones and those of the Burralow Formation (Text-fig. 2).

Petrography of Grose Sandstone Rocks.—The sandstones vary in average grainsize between 0·1 and 0·3 mm. The average roundness, on visual estimation, varies between 0·4· and 0·7, the mode lying between 0·5 and 0·6. Individual grains may give values of 0·1 to 0·9. The effect of secondary enlargement *in situ* has not been taken into account, and is very difficult to assess. The cement is invariably clay mineral, with minor amounts of quartz in some cases. Two constituents are prominent throughout the Formation, quartz and rock fragments. This gives the rocks a rather distinctive appearance in thin section.

Under the binocular microscope the quartz grains are of fairly high sphericity, and are transparent to translucent, generally with a frosted rough surface. A few grains exhibit a frosted smooth surface. Facets, due to secondary

enlargement, are frequent, though they are not always well developed.   Drusy surfaces have been noted.   The grains are orange, yellow or, rarely, amethyst.

In thin section the quartz is of very variable shape and roundness.   The grains may be simple or composite, the former predominating.   Occasionally composite grains show a " ladder vein " structure, wherein the c-axes of the components are all parallel and perpendicular to a given plane.   The grains may show secondary enlargement and sutured margins.

The extinction is either abrupt or undulose.   The latter is found in most composite grains, but is also seen in many simple grains.   Dusty inclusions, bubble trails, rutile needles, occasional blebs and veins of chlorite and inclusions of tourmaline, muscovite, (?) zircon and (?) apatite are present, the tourmaline and muscovite being very frequent.   Rare second cycle grains are met with.

The quartz in these rocks was probably derived from an area of plutonic rocks and quartz veins which had been stressed.

Well rounded rock fragments are numerous, the types present being " chert ", which consists of a fine quartz mosaic, and which is partly of radiolarian origin ;   argillites of various types—quartz-sericite siltstone, sericite schist, quartzose siltstone, mica schist and a (?) kaolinitic argillite.   This latter, which occurs throughout the Narrabeen Group, consists of an aggregate of stumpy vermicular " crystals " of high relief and low birefringence.   The grainsize is too small to permit determination of detailed optics, but the mineral is evidently a chlorite or kaolinite.   Vitric tuff fragments are present in nearly every sand-stone, and occasional fragments of a feldspathic volcanic occur.

Muscovite is present in all specimens and the flakes are often bent.   Odd grains of alkali feldspar occur and fragments of pale green chlorite are generally to be found.   Occasional decussate patches of muscovite, which may be due to the comminuting of larger flakes, have been noted.   The heavy minerals include tourmaline, zircon, rutile and iron ores.   It is proposed to deal with these in more detail in a separate paper.   In some cases authigenic carbonate, probably siderite or ankerite, has developed.   This is now almost entirely replaced by iron oxides.

The cement consists of (?) kaolinite, in tabular crystals of high relief and low birefringence, and " illite ", a brown chloritic mineral with birefringence 0·010.

A specimen of sandstone from Govett's Leap shows certain significant differences from the more widespread type.   It contains only simple quartz grains, showing either abrupt or undulose extinction.   Chlorite, of birefringence 0·007, is well developed as pale green books and sheaves, in part acicular radiating.   The rock fragments are more abundant than further east, and consist largely of devitrified vitric tuff.

The red siltstones consist of fairly coarse silt, with grains 0·04 mm. diameter and an iron oxide cement.   The abundant quartz grains are simple, some showing undulose extinction.   Muscovite and sericite are widespread.   The bright red to red-brown cement probably contains chlorite and clay mineral coated with iron oxides.

Burralow Formation (nov.).   Named from Burralow Creek, along the valley of which the Formation is well developed.

Thickness : Maximum observed, 454 ft.

Type Section : No. 15 at 624463 Windsor.

Reference Section : No. 19 at 601518(.5) Windsor, containing the type exposure of the Tabarag Sandstone Member.

The Formation is a mixture of rock types, mainly quartz-rich sandstones, grey shales and red-brown claystones, with grey chloritic claystones and ortho-quartzites as minor constituents.   The succession is rather variable.

The Formation attains its maximum observed thickness in the Springwood Creek district, whence it thins somewhat to the north-east and east, and markedly to the west. In the lower Grose Valley its thickness is between 250 ft. and 300 ft.

In the west of the area the Formation is represented by a few feet of red-brown claystone, as at Govett's Leap, although a small amount of grey shale and sandstone are present in the Clarence Bore, where the Formation is 34 ft. thick.

To the east the Formation thickens fairly rapidly, being 150 ft. at 516515 Windsor on the Grose upstream from Hungerford's Creek (Section No. 2, Text-fig. 3). Here the equivalents of the Gosford Formation (i.e. the beds between the top red-brown claystone and the Hawkesbury Sandstone) are missing, as there is a 3 ft. bed of claystone immediately under the sandstone. It is likely that four claystone beds are present in this section. It is peculiar in this, and in the presence of red siltstone low in the sequence, and also in the absence of any thick sandstones.

A section on the Grose just south of Wentworth Creek (No. 3) shows the Formation to have thickened to 257 ft. From here it continues to thicken evenly to Springwood Creek. This section is the first, coming eastwards, to show thick sandstones in the sequence. The red-brown claystones lie beneath these sandstones.

In the next section (No. 4) the claystones are between the sandstones, and in the next (No. 5) they are, in part, above. Further to the east they are intimately associated with what is probably the Tabarag Sandstone Member (Sections Nos. 13–17). Here one bed is sandwiched between the sandstones, whilst the other is beneath the lower sandstone. In this area on the Grose, east of Burralow Creek, there is a bed of claystone immediately above the Grose Sandstone, a feature which has also been observed at Wheeny Gap.

Along Burralow Creek the picture is similar (Text-fig. 4), although the heavy talus cover makes correlation difficult. Here at least two, and possibly three, beds of claystone occur, their position in the column being variable. The bed shown in Section No. 20 is known to be discontinuous.

The best development of the claystones is on the Grose River (Section No. 17), where the topmost is 30 ft. thick. Slightly west of here thicknesses of 17 ft. and 24 ft. are recorded (Section Nos. 15 and 14).

Frequently the claystones are associated with a grey claystone or mudstone which is identical macro- and microscopically with the mudstones of the Caley Formation. Usually the red-brown claystone grades up into the grey, as in Section No. 14, and rarely downwards also. Or, as in Section No. 5, the grey may be present as an interbed. The junction is always gradational, and results in mottled claystones.

Lenticular orthoquartzites are of sporadic occurrence throughout the Formation. At their best point of development, on the south end of Tabarag Ridge, they form beds up to 3 ft. thick (Section No. 19). They are dense hard fine-grained rocks, usually white, and show pitted bedding surfaces and traces of plant debris.

Fissile grey shales are widespread. They frequently contain comminuted plant debris, and specimens of *Phyllotheca* sp. have been observed.

The sandstones are quartz-rich, being either quartzose or sub-labile. Labile varieties are very rare. In outcrop they are brown or orange, but some may be purple. Their grainsize varies from fine to coarse, and some verge on fine conglomerates. Many are massive and cliff-forming, but fissile shaley varieties occur. Cross-stratification is common, and is similar to that in the Grose Sandstone. Ripple marks are known.

Individual sandstone beds within the Formation may be 40 ft. thick, one of the thickest being the Tabarag Sandstone Member, on Burralow Creek (Section No. 16), which is 75 ft. This Member, which is massive and quartz-rich, forms prominent cliffs along the upper portions of Burralow Creek, and is well developed on the south end of Tabarag Ridge, whence it takes its name. It caps the end of the ridge above the road as it curves around the southern end.

As the Member is not lithologically different from other sandstones in the Formation, correlation has proved difficult in talus covered areas. For this reason the correlation shown in Text-figure 4 should be taken as provisional.
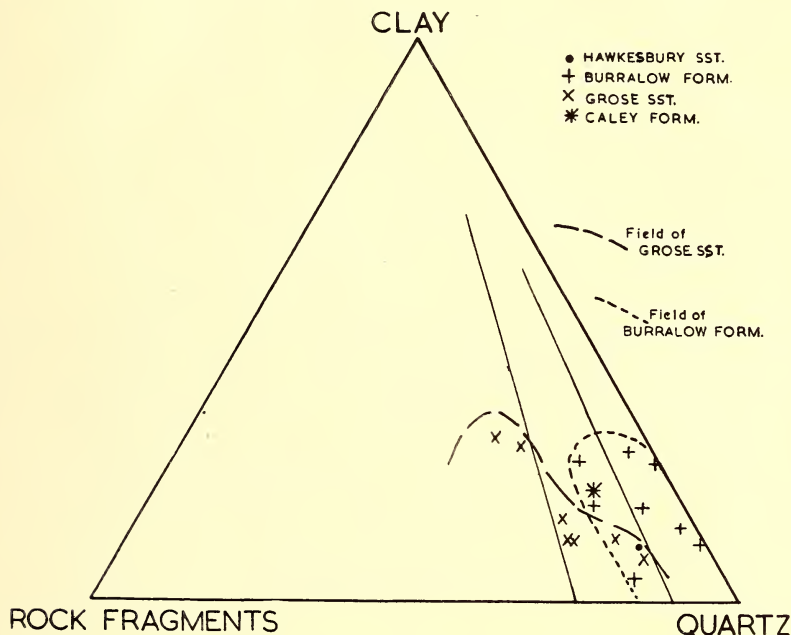
Text-fig. 2.

The Burralow Formation has been little examined outside the Grose River district, but it is known that it can be differentiated without difficulty at least as far north as the Colo River. Good outcrops occur along Lagoon Creek, south of Mountain Lagoon, and at Wheeny Gap.

Petrography of Burralow Formation Rocks.—The sandstones vary from fine to coarse, average grainsizes being between 0·08 mm. and 0·8 mm. The sorting is frequently poor, giving an uneven appearance in thin section. The roundness of individual grains may be as high as 0·9, but the average, making no allowance for secondary enlargement, is generally in the range 0·3–0·6, the mode lying between 0·4 and 0·5. The cement and authigenic minerals are similar to those of the Grose Sandstone.

Quartz is the most prominent constituent of these rocks, and differs little from that in the Grose Sandstone. Under the binocular microscope it was observed that, while most of the grains were transparent and colourless, trans-

FIG. 3 STRATIGRAPHIC COLUMNS OF THE TRIASSIC IN THE GROSE VALLEY.

Text-fig. 3.

lucent grains were white or yellow, and developed smaller secondary facets. In thin section some of the grains appear to be fragments of fine orthoquartzite, but second cycle grains are rare.

Rock fragments, a minor constituent in these rocks, consist exclusively of argillites. Shaley sandstones (GR12) contain appreciable amounts of shale, which consists of chlorite, clay minerals, sericite and silt-size quartz.

The accessory minerals are similar to those in the Grose Sandstone, but significant differences in the proportion of the various heavy mineral species occur.

The orthoquartzites are fine-grained, some being siltstones (GR50). They differ from fine quartzose sandstones in both appearance and cementation. They are not friable and have the sugary surface appearance characteristic of quartzite. This is due to a welding together of the constituent grains by the deposition of secondary quartz.

The orthoquartzites are well sorted and have an average grainsize between 0·07 and 0·1 mm. Roundness values are indeterminable, but the sphericity is high. The cement is dominantly quartz with minor clay minerals.

Quartz, in simple grains, is the dominant constituent. It shows abrupt, or less commonly, undulose extinction. Sutured margins are common, giving a mosaic pattern to the rock, and inclusions of chlorite, (?) zircon and tourmaline and fine dusty inclusions are present.

Rock fragments, with the exception of very rare chert grains, are absent. Muscovite and sericite are widespread and small amounts of orthoclase, chlorite and biotite have been noted. The heavy minerals consist of yellow and blue tourmaline, iron ore, zircon and rutile. Patches and discrete crystals of authigenic siderite which alters to iron oxides occur in the siltstones.

The quartzose siltstones are coarse silts, similar in many ways to the sandstones, but with a simplified mineral assemblage. They consist of quartz, muscovite, sericite, clay minerals, zircon and blue tourmaline. The quartz is of variable roundness, and may be very elongated. Both simple and composite grains are present, and the extinction may be abrupt or undulose. Discrete crystals, aggregates or spherulites of authigenic siderite are widespread. These alter marginally to iron oxide.

Hawkesbury Sandstone, Clarke, 1848. (*Vide* Hanlon *et al.*, 1952.)

This Formation attains a maximum thickness in this area of about 780 ft. at Kurrajong Heights. It thins appreciably to the west, due partly to erosion and partly to the general thinning of the sequence towards the edge of the basin. To the north-west of Bilpin the regional dip rapidly takes the base of the Formation above the general plateau level, so that it occurs mainly as outliers on high points.

Lithologically the formation differs little from that in other parts. It is a massive quartz-rich sandstone, cliff-forming, and showing good cross-stratification. Occasional shale lenses are present (Section No. 2), and the basal two feet are frequently conglomeratic, the pebbles being exclusively vein quartz.

Petrographic Analyses.

Table I sets out the results of a series of micrometric analyses of sandstones from the various formations, which are plotted on a triangular diagram in Text-figure 2. A partial separation is obtained between the sandstones of the Grose Sandstone and the Burralow Formation. This reflects the differing composition of the two formations. Sandstones of the Grose Sandstone are

G

FIG. 4. STRATIGRAPHIC COLUMNS OF THE TRIASSIC ALONG BURRALOW CREEK

Text-fig. 4.

labile to sub-labile, whilst those of the Burralow Formation are sub-labile to quartzose.

Pettijohn (1954) has discussed several factors which seem important in the classification of sandstones. While his classification is not used herein, that of Packham (1954) being preferred, consideration will be given to the factors he has discussed. These are the " provenance factor ", the " maturity factor " and the " fluidity factor ".

Considering first the provenance factor, which is the ratio of feldspar to rock fragments, one is immediately struck by the absence of feldspar in these rocks. This would argue for a source deficient in feldspar. Since the rock fragments are largely low-grade metamorphics, and the quartz is either of vein or plutonic origin, it might be assumed that the rocks were derived from a non-granitic terrain composed of low-grade argillites containing abundant quartz veins. Fragments of vitric tuff are explainable by reworking of portions of the Permian sequence.

TABLE I.

Micrometric Analyses of Sandstones.

Spec. No.	Form.	Length Trav.	Quartz.	Rock Frag.	FeO and +CO₃.	Misc.	Chlorite.	Clay Cement.
		mm.	%	%	%	%	%	%
GR8	Burr.	55·83	76·1	6·1	2·0	0·4	—	15·1
GR12	Burr.	122·47	62·1	9·8	6·7	0·9	2·0	18·5
GR29	Hawk.	127·93	79·4	10·3	4·3	0·5	—	5·6
GR37	Burr.	91·14	83·4	2·3	3·0	0·7	—	10·6
GR40	Burr.	85·76	88·6	0·8	1·3	0·3	—	9·0
GR41	Burr.	112·87	67·4	13·7	6·3	1·6	—	11·0
GR44	Burr.	135·64	74·7	0·2	20·5	—	—	4·6
GR56	Grose	110·93	68·6	19·7	2·0	0·8	—	8·9
GR59	Grose	105·98	47·8	20·5	—	0·2	2·3	29·2
GR60	Grose	118·95	49·7	19·5	1·3	2·7	—	26·8
GR66	Grose	111·28	67·8	22·8	—	0·3	0·1	9·0
GR76	Burr.	123·59	82·0	13·5	—	—	0·4	4·1
GR79	Grose	117·49	64·7	19·6	3·4	0·5	—	11·8
GR97	Burr.	109·51	69·4	1·3	1·7	—	2·2	25·4
GR113	Caley	112·46	67·6	12·5	1·4	—	—	18·5
GR116	Grose	101·19	75·2	13·0	0·5	0·1	—	11·2
GR117	Grose	93·54	81·3	11·9	0·2	—	—	6·6

The above explanation holds only if the relative instability of feldspar and argillite fragments was equal under the conditions of erosion and deposition. Were this not so it is possible that the source terrain was rich in feldspar, but the latter has been destroyed by weathering and during transport.

Considering the composition of the rocks of the Burralow Formation and Grose Sandstone there seems little evidence for difference of source. The greater percentage of quartz in the former Formation may reflect an increase in quartz available in the source area, but is more probably a function of the maturity of the sediment.

The maturity factor, which is the ratio of quartz and chert to labile detrital material, shows well the differences between the two formations. This factor varies, in round figures, between 2 and 7 for the Grose Sandstone and 5 and 350 for the Burralow Formation. The greater maturity of the Burralow Formation sandstones may be explained by a longer period of transport and reworking, or by partial derivation of the sediment from preexisting unconsolidated deposits, such as the Coal Measures or the Caley or Grose Formations.

The fluidity factor, which is a function of the percentage of detrital clay, seems of little importance in these rocks since they are undoubtedly the result of traction current deposition.

CORRELATION.

Owing to a complete absence of suitable fossils it is not possible to establish synchroneity of beds. Such correlations as may be made are purely lithological. It has been argued in some quarters that the red-brown claystones may represent a time-stratigraphic plane, but, while this may be broadly true, it will not hold for individual beds.

TABLE II.

Correlation of Narrabeen Group between Colo-Grose and Narrabeen-Wyong Districts.

Colo-Grose District.	Narrabeen-Wyong District.
Burralow Formation (with Tabarag Sandstone Member).	Gosford Formation.
	Collaroy Claystone.
Grose Sandstone.	Tuggerah Formation.
Caley Formation.	Munmorah Conglomerate.

Table II gives the proposed correlation between the Narrabeen Group in the Grose Valley and Narrabeen-Wyong districts. The correlation is more tentative in the lower portions. There is no doubt that the upper portion of the Burralow Formation, above the topmost red-brown claystone, is the lithological equivalent of the Gosford Formation.

The correlation of the top of the Grose Sandstone and the top of the Tuggerah Formation is based on the occurrence of 119 ft. of sandstone and conglomerate at the top of the latter formation in Windeyer's Hawkesbury River Bore (Hanlon *et al.*, 1954, p. 118).

Correlation lower in the sequence is rendered difficult by the dissimilarity of the two sequences. No conglomerates have been observed in the Narrabeen Group in the Grose Valley, although they are recorded in the Clarence and Woodford Bores. On relative thicknesses it might be safely assumed that portions of the Grose Sandstone and the Munmorah Conglomerate are lithologically equivalent.

Table III shows a tentative correlation between the Grose Valley and South Coast. Although superficially the successions are similar, this is probably fortuitous, since the South Coast is characterized by lithic sandstones, poor in quartz, about 10–20% being frequent (Hanlon *et al.*, 1954, p. 113), and green shales. The source of sediment for the South Coast was probably widely separated from that of the Grose Valley sequence. It is obvious that considerable advances in our knowledge of the Narrabeen Group in the southern Blue Mountains and between Burragorang Valley and the coast will be necessary before the relationship between the compositionally different sequences of the west and south can be understood.

Text-figure 1 represents an attempted correlation between the Grose Valley section and sections in other parts of the Blue Mountains. The Burralow Formation is thinning to the south and west. Its non-appearance in the Evan's

REFERENCE

	Quaternary	Recent Alluvium
		? Pleistocene Lacustrine Sands
	Tertiary	Basalt
		Volcanic Agglomerate
		Bringelly Shale
	Wianamatta Group	Minchinbury Sandstone
		Ashfield Shale
	Triassic	Hawkesbury Sandstone
		Burralow Formation
	Narrabeen Group	Grose Sandstone
		Caley Formation
	Permian	Lithgow Coal Measures
	Talus Cover	

Roads
Well being drilled
Dykes
Probable Dykes
F —— F Fault
No of Strat. Column on Fig 3 & 4

Scale in Miles

0   ¼   ½   ¾   1   2   3

MAP 1

GEOLOGICAL MAP of the KURRAJONG - GROSE RIVER DISTRICT

Text-fig. 5.

Lookout section is quite anomalous, and may be due to incorrect observations. In the west the Formation is dominated by red-brown claystone.

The Grose Sandstone thins to the west, as does the Caley Formation. To the south, however, the Caley Formation is thickening. To the north-west of the area examined aerial photographs show that the plateau surface is cut into successively lower beds in the sequence, and it therefore seems certain that the massive sandstone cliffs overlying the Coal Measures along the Mudgee railway line are stratigraphic equivalents of the Grose Sandstone.

TABLE III.

Correlation of Narrabeen Group between Colo-Grose and South Coast Districts.

Colo-Grose District.	South Coast District.
Burralow Formation.	Gosford Formation.
	Bald Hill Claystone.
Grose Sandstone.	Bulgo Sandstone.
	Stanwell Park Claystone.
	Scarborough Sandstone.
Caley Formation.	Wombarra Shale.
	Coalcliff Sandstone.

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Sections Nos. 1, 2, 3, 7, 15 and 19, which follow, are representative. Complete details are incorporated in the author's M.Sc. Thesis, which is lodged in the Department of Geology and Geophysics, University of Sydney.

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STRATIGRAPHIC COLUMNS IN THE TRIASSIC.
(Tbg. Sst. = Tabarag Sandstone Member.)

SECTION NUMBER : 1.   LOCALITY : 439(.5)487(.5) Katoomba.
(Absolute heights approximate only.)

Stratigraphic Name.	Lithology.	Thickness.	Height A.S.L. Base.
		Feet.	Feet.
Grose Sandstone. 400+ feet.	Medium to coarse quartz-rich sandstones, frequently cross-bedded, containing interbeds of grey shale to 10 feet thick ; also red siltstones (GR112) as at .. .. .. Base at	400+	963 917
Caley Formation. 100+ feet.	Fissile grey shale.. .. .. Medium-grained quartz-rich sandstones (GR113) with cross-bedding. No visible interbeds .. .. Further grey shales	62 30 ?	855 825 ?

SECTION NUMBER : 2.   LOCALITY : 516515 Windsor.
(Absolute heights approximate only.)

Stratigraphic Name.	Lithology.	Thickness.	Height A.S.L. Base.
Hawkesbury Sandstone. 250+ feet.	Medium to coarse quartz-rich sandstones .. Pebbles of vein quartz to 1 inch diameter in basal 2 feet. Contains interbeds of grey shale to 10 feet thick, as at	250+	897
Burralow Formation. 150 feet.	Red-brown claystone .. .. Interbedded grey shales, frequently sandy, and fine sandstones, quartz-rich .. .. Massive quartz-rich sandstones .. .. Red-brown claystone, mottled .. .. TALUS .. .. Red-brown claystone .. .. TALUS .. .. Red-brown claystone .. .. Interbedded grey sandy shales and sandstones, GR115, with beds of red siltstone, GR114, near base	3 18 4 10 26 5 18 4 59	873 828 806 747
Grose Sandstone. 300+ feet.	Medium to coarse creamy-white quartz-rich sandstone, GR116, with frequent cross-bedding. Some bands of interbedded shale and sandstone at .. .. Base not exposed	 300+	591

STRATIGRAPHIC COLUMNS IN THE TRIASSIC.—*Continued.*
(Tbg. Sst. = Tabarag Sandstone Member.)

Section Number : 3. Locality : 554479(.5) Windsor.
(Absolute heights approximate only.)

Stratigraphic Name.	Lithology.	Thickness.	Height A.S.L. Base.
		Feet.	Feet.
Hawkesbury Sandstone.	Medium to coarse white quartz-rich sandstone, strongly cross-bedded		859
Burralow Formation. 257 feet.	Grey shale, fissile, partly talus covered ..	19	840
	Medium to coarse white quartz-rich sandstone	30	810
	Fissile grey shales, upper portions talus covered	33	777
	Massive creamy-white medium to coarse quartz-rich sandstone, very coarse at top, and flaggy with some shale in middle ..	50	727
	Talus	10	
	Fine flaggy sandstone	4	713
	Talus	57	
	Medium massive quartz-rich creamy white sandstone	3	
	Red-brown claystone	3	650
	Interbedded gray fissile shales and fine sandstones, quartz-rich	29	621
	Red-brown claystone	4	617
	Fissile gray shales and flaggy sandstone, quartz-rich, fine and white	15	602
Grose Sandstone.	Medium to coarse creamy-white quartz-rich sandstone, GR117, buff weathering and cliff-forming. Cross-bedding prominent at many points. Base not exposed	300+	

Section Number : 7. Locality : 605462 Windsor.

Burralow Formation.	Massive quartz-rich sandstone..		576
	Grey shales	20	556
Grose Sandstone.	As before (GR60)	550+	

STRATIGRAPHIC COLUMNS IN THE TRIASSIC.—*Continued.*
(Tbg. Sst. = Tabarag Sandstone Member.)

SECTION NUMBER : 15. LOCALITY : 624463 Windsor.

Stratigraphic Name.	Lithology.	Thickness.	Height A.S.L. Base.
		Feet.	Feet.
Hawkesbury Sandstone.	Coarse to medium grained quartz-rich sandstone, cliff-forming		419
	Grey clay shales with sandstone interbeds ..	57	362
	Fine grained, soft, quartz-rich sandstone ..	4	358
	Grey shales, fissile, and with sandstone interbeds	81	277
	(Tbg. Sst.) { Massive quartz-rich sandstone, medium grained (GR85), flaggy towards top	18	259
	Red-brown claystone	17	242
	Massive quartz-rich sandstone, coarse at base, medium-grained above (GR4) ..	45	197
Burralow Formation. 350 feet.	Grey claystone	10	
	Red-brown claystone (GR6)	17	170
	Fissile grey shales with interbedded sandstones ; shales frequently silty (GR7) ..	14	
	Fine sandstone, silty near top (GR8)..	4	
	Grey shale (GR10)	4	148
	Fine conglomerate (GR9)	2	
	Shales with interbedded sandstones (GR11), frequent towards top	54	94
	Flaggy sandstone, with shale pebbles (GR12)..	6	
	Shales with fine sandstones (GR13) ..	16	72
	Red-brown claystone (GR14)	3	
Grose Sandstone.	Massive, cross-bedded quartz-rich sandstone (GR15)		69

SECTION NUMBER : 19. LOCALITY : 60158(.5) Windsor.

	Dip : 30°.		
Hawkesbury Sandstone.	Massive sandstone		1376
	Shale, brown and grey, micaceous ..	20	1356
	Massive cliff-forming quartz-rich sandstone (Tbg. Sst.)	51	1305
	TALUS	52	1253
	Possible bed of quartz-rich sandstone.. ..	6 (?)	1247
	TALUS	22	1225
	Coarse-medium cliff-forming quartz-rich sandstone	21	1204
	TALUS		1175
	Grey shales, fissile	2+	1173
	Medium quartz-rich sandstone	4	1169
	Grey shales and fine fissile silty sandstones ..	8	1161
Burralow Formation. 304 feet.	Coarse quartz-rich sandstone	6	1155
	Grey fissile shales and orthoquartzites ..	4	1151
	Coarse quartz-rich sandstones	1	1150
	Grey fissile shales and orthoquartzites ..	9	1141
	Red-brown claystone	1	1140
	Grey shales with white interbeds, and lenticular orthoquartzites, latter becoming more prominent towards top 3 feet bed at 1117 feet)	43	1097
	Medium quartz-rich sandstone	7	1090
	Chloritic claystone	4	1086
	Quartzites and fine quartz-rich sandstones with interbedded grey shales. Base not exposed		1072

ON THE ASSOCIATION OF ALBITITES AND SODA APLITES WITH POTASH GRANITES IN THE PRECAMBRIAN AND OLDER PALÆOZOIC OF AUSTRALIA.

By GERMAINE A. JOPLIN.

Department of Geophysics, Australian National University.

ABSTRACT.

In this short paper attention is drawn to the not uncommon association of small masses of albitite and of soda aplite with potash granites in several parts of Australia. Furthermore, all these occurrences seem to be of Precambrian or of Older Palæozoic age and, so far as is known, no rocks which can be referred to as albitites occur among the younger igneous rocks.

Elsewhere in the world albitites are commonly associated with basic and ultrabasic rocks and do not appear to be confined to the older formations.

INTRODUCTION.

Recent work on the Precambrian in the Cloncurry Mineral Field of Queensland has shown that small masses of albitite and soda aplite are of very common occurrence, and a search of the literature has revealed that these types are not uncommon among the Precambrian and Older Palæozoic rocks elsewhere in Australia, whereas they are rare among the later igneous rocks. Actually albite-bearing rocks are common throughout the geological succession, but most of these can be shown to have resulted from a process of albitization and few can be defined as either an albitite or a soda aplite.

Holmes (1920) defined an albitite as " a leucocratic soda-syenite or porphyry composed wholly of albite ", and this rock type is of comparatively rare occurrence throughout the world. The rock originally named an albitite was described from the Trias-Jura of Sierra Nevada (Turner, 1896) and another well known example occurs in the Ural Mountains (Duparc and Pamfil, 1910) and is of Permian age. In many parts of the world albitites occur with corundum (Larsen, 1928) and in every case these albitites are associated with basic or ultrabasic rocks.

The Australian albitites and soda aplites, however, are mostly associated with potash granites and where basic rocks do occur the association can be shown in some instances to be fortuitous.

It is true that the Precambrian albite-porphyries and albite-porphyrites of Western Australia are associated with dolerites, but this group of rocks has been critically examined and appears to bear no relation to the rocks considered in this paper. Furthermore, Prider (1940) and others believe them to be the result of albitization. Actually both albitites and soda aplites may also have resulted from albitization and their origin, which is far from clear, is discussed below.

Thus the Australian examples appear to be unique in two respects : first that in many places they are associated with potash granites, and secondly, that they appear to be confined to the older igneous rocks.

<center>FIELD RELATIONS.</center>

In the Cloncurry Mineral Field of Queensland albitites and soda aplites are closely associated and appear to grade one into the other. These igneous bodies are always small, though in places they may be numerous. West of Mt. Isa, on Kitty's Plain, several dykes of both types occur, and at least one of these invades the Proterozoic potash microgranite (Joplin, 1955). Others occur as small irregular masses among the pre-granite basic rocks and have suffered different degrees of basification. They must therefore post-date potash granite and basic country rock, and their association with the basic is merely a fortuitous one. North of Rifle Creek small irregular and dyke-like masses invade metamorphosed sediments, and in the Soldier's Cap area these rocks occur as a series of small sheets among high-grade pelites.

In South Australia an albite syenite, very similar to the Mt. Isa albitite, is associated with potash granite at Encounter Bay (Browne, 1920) and dykes of soda aplite, apparently associated with uralitized dolerite, occur in the same district.*

On Kangaroo Island, albitites are also associated with potash granite (Tilley, 1919) and Jack (1914) has described dykes of albitite from Eyre Peninsula. One of these contains large crystals of scapolite, suggesting a limestone contamination, but the field relations are not discussed. These three South Australian occurrences are possibly of Cambrian age (David, 1950).

In the Broken Hill area of New South Wales Browne (1922) has described soda aplites which invade the Platy Gneiss, actually a potash granite. Both rocks are considered to be of Precambrian age.

On the Pilbara Goldfield of Western Australia an albite pegmatite dyke invades granite (Maitland, 1904). The pegmatite contains tin and its chemical composition is very similar to that of an albitite (see Table I, Anal. 5). Woodward (1908) also describes staniferous albite pegmatites penetrating granite which forms belts within the greenstone area of the Greenbushes Tinfield of Western Australia.

A small mass of highly contaminated albitite occurs on the margin of the Proterozoic Fenton Granite about 110 miles south-south-east of Darwin in the Northern Territory.

In different parts of South Australia and in Gippsland, Victoria, quartz-keratophyres occur (Skeats, 1909 ; Howchin, 1916 ; Thiele, 1916 ; Teale, 1920 ; Mawson and Dallwitz, 1944, 1945). Chemically these compare with the soda-aplites, and though no relationship to granite has been established, potash granite occurs in fairly close proximity. As many of the keratophyres are extrusive there is much to suggest that they may be albitized rhyolites and though the chemical similarity to the soda aplites is quite remarkable they cannot be compared with them texturally, mineralogically or in their field occurrence. The age of the keratophyres may range from Ordovician to Devonian.

Thus there is field evidence to suggest that the albitites and albite syenites are related to the soda aplites and that both suites may be related to the potash granites.

<center>MINERALOGICAL AND CHEMICAL CHARACTERS.</center>

The albitites and albite-syenites are pure white rocks of somewhat uneven grainsize. In most cases they are fine with an occasional large grain, but in places they may be porphyritic. The fabric is granitic, and they contain about 90 per cent. of felspar which is almost wholly albite (ranging from Ab_{100} to Ab_{92}),

_____

* Dr. Browne now considers that this association is possibly fortuitous and that there is no genetic connection between the soda aplites and dolerites.—Personal communication.

though a few grains of microcline have been noted in some specimens. The albite is the type known as checker or check-board albite. This structure is usually considered to be a type of twinning but recently Niggli (1954) has suggested that it is an interpenetration due to replacement.

Mr. N. J. Snelling, of this Department, very kindly determined a number of felspars by the 5-axis method of Emmons and found that the poles to the composition planes fall on the low temperature migration curves (Tröger, 1956).

TABLE I.

Albites and Albite-syenites.

	I.	II.	III.	IV.	V.
SiO_2	67·84	66·13	68·39	64·60	68·36
Al_2O_3	20·42	19·92	—	20·37	18·74
Fe_2O_3	0·01	0·60	—	0·31	Abs.
FeO	0·32	0·19	—	0·67	1·15
MgO	0·14	0·12	—	1·15	0·54
CaO	0·67	0·57	0·65	0·41	0·39
Na_2O	9·54	10·83	11·22	9·94	10·22
K_2O	0·51	1·02	0·21	0·16	0·07
H_2O+	0·07	0·30	0·45	0·85	0·03
H_2O-	0·06	0·14	—	0·15	Abs.
TiO_2	0·18	0·31	—	1·04	—
P_2O_5	Tr.	0·09	—	0·22	—
MnO	Tr.	—	—	—	0·45
CO_2	—	0·40	—	Tr.	—
FeS_2	—	0·05	—	Abs.	—
ZrO_2	—	—	—	0·03	—
Cl	—	0·03	—	—	—
	99·76	100·70	—	99·90	100·02
Sp. Gr.	2·595	—	—	2·635	—

I. Albitite, Kitty Plain, May Downs near Mt. Isa, Queensland. Anal. G. A. Joplin. *Trans. Roy. Soc. Queensland*, 66, 54, 1955.
II. Albitite, Sec. 40, Hundred of Roberts, Eyre Pen., South Australia. Anal. W. S. Chapman. *Geol. Surv. S.A.*, Bull. 3, 16.
III. Albitite, Cape Willoughby, Kangaroo Island, South Australia. Anal. C. E. Tilley. *Trans. Roy. Soc. S.A.*, 44, 1920.
IV. Albite-mica-syenite, Rosetta Head, Encounter Bay, South Australia. Anal. W. R. Browne. *Trans. Roy. Soc. S.A.*, 44, 23, 1920.
V. Albite Pegmatite (tin matrix) Moolyella, Pilbara Goldfield, Western Australia. Anal. E. S. Simpson. *Geol. Surv. W.A.*, Bull. 15, 12, 1904.

These rocks may contain up to about 10 per cent. of quartz, but it is commonly less abundant and with an increase in the quartz content the rocks pass into soda-aplites. In many cases the quartz is graphically intergrown with the albite, a feature more common in the quartz-rich types. Accessory minerals are muscovite, bleached biotite or chlorite, tourmaline ilmenite or rutile.

In the Mt. Isa district some of the albitites are hybridized by the basic rocks which they invade, and in some cases they may be contaminated by quartzite (Joplin, 1955). The occurrence of scapolite in an albitite from Eyre's Peninsula suggests contamination by limestone and the white, felspathic rock on the margin of the Fenton Granite in the Northern Territory is so much

contaminated by limestone that it cannot be called an albitite and consists mainly of altered basic andesine and epidote (see Table II, Anal. 1).

The soda-aplites differ from the albitites only in that they contain a very much higher percentage of quartz with concomitant decrease in felspar ; furthermore, the proportion of potash felspar to soda felspar is higher in these rocks. At Mt. Isa some of the soda-aplites are hybridized by the basic rocks that they invade, and in such types chlorite is abundant.

Chemically the albitites and albite syenites are characterized by an average silica percentage of about 67, a soda percentage of about 10 and a potash percentage of about 0·4 (see Table I). Reference to Table IV will show that the ratio of soda to total alkalis ranges from 91·4 to 99·3 per cent., with an average of 96·4 per cent.

TABLE II.

	I.	II.	III.	IV.
SiO_2 ..	54·23	61·95	49·82	76·67
Al_2O_3 ..	27·80	22·02	14·46	13·29
Fe_2O_3 ..	0·42	0·82	4·78	0·42
FeO ..	0·23	0·51	6·75	0·56
MgO ..	0·09	3·98	5·42	0·01
CaO ..	8·94	3·02	9·86	0·17
Na_2O ..	6·48	6·13	4·98	4·34
K_2O ..	0·37	0·45	0·44	3·27
H_2O+ ..	0·28	0·80	0·81	0·26
H_2O- ..	0·30	0·09	0·05	0·09
TiO_2 ..	0·03	0·51	2·33	1·16
P_2O_5 ..	0·49	n.d.	1·02	Tr.
MnO ..	Tr.	0·01	0·14	0·01
	99·66	100·29	100·86	99·95
Sp. Gr. ..	2·753	2·649	2·995	2·639

    I. Felspathic Rock (Contaminated Albitite). Edge of Fenton Granite, 110 miles south-south-east of Darwin, Northern Territory. Anal. G. A. Joplin.

   II. Hybridized Albitite, Kitty's Plains, 5½ miles east of old Homestead, May Downs, Mt. Isa, Queensland. Anal. G. A. Joplin. *Trans. Roy. Soc. Queensland*, 66, 54, 1955.

  III. Albitized basic rock, same locality as II. Anal. B. E. Williams. *Ibid.*

  IV. Albitite contaminated by Quartzite. Same locality as II. Anal. J. K. Burnett. *Ibid.*

The soda-aplites (Table III) have an average silica percentage of about 75, a soda percentage of slightly over 6, with potash rather variable. Omitting the leucogranite (Table III, Anal. V), the ratio of soda to total alkalis averages 94 per cent. Except for high soda, no chemical characters can be laid down for the hybrid and contaminated rocks, as the composition of assimilated material ranges from sedimentary quartzites and limestones to basic igneous rocks.

ORIGIN OF THE ALBITITE-RICH ROCKS.

The field, mineralogical and chemical evidence points to a close genetic relationship between the albitites and soda-aplites.

In the Mt. Isa, Encounter Bay, Kangaroo Island, Broken Hill, Fenton and Pilbara areas the soda-rich rocks are closely associated with potash granites, and this may be significant.

TABLE III.

Soda-aplites.

	I.	II.	III.	IV.	V.
SiO_2 ..	75·30	77·68	76·02	71·56	76·90
Al_2O_3 ..	14·80	13·04	14·60	17·74	13·75
Fe_2O_3 ..	0·25	0·02	0·27	0·30	0·34
FeO ..	0·14	0·09	0·08	0·86	—
MgO ..	0·03	1·52	0·04	Abs.	0·22
CaO ..	0·07	0·11	0·34	0·38	0·20
Na_2O ..	6·70	5·03	7·08	7·54	6·26
K_2O ..	0·12	0·46	0·96	0·78	2·78
H_2O+ ..	0·25	0·61	0·34	0·47	0·15
H_2O- ..	0·21	0·04	0·17	0·15	0·05
TiO_2 ..	1·12	1·15	0·07	0·38	0·03
P_2O_5 ..	Abs.	Abs.	—	0·03	Abs.
MnO ..	Abs.	Abs.	—	0·01	Abs.
CO_2.. ..	0·97	—	—	—	—
FeS_2 ..	—	—	—	0·08	—
F	—	—	—	—	—
	99·96	99·93	99·95	100·28	100·68
Sp. Gr. ..	—	—	2·626	—	—

   I. Soda-aplite, 3 miles South of junction of East and West Branch of Snake Creek, Soldier's Cap Area, Queensland. Anal. J. K. Burnett.
  II. Soda-aplite, Kitty's Plain, May Downs, Mt. Isa, Queensland. Anal. J. K. Burnett.
III. Soda-aplite, Port Elliot, Encounter Bay, South Australia. Anal. W. R. Browne. *Trans. Roy. Soc. S.A.*, 1920, 44.
IV. Soda Granite, Radium Hill, South Australia. Anal. W. S. Chapman. *Ibid.*, 1944, 68, 338.
  V. Albite-microcline-leucogranite. The Pinnacles, Umberatana, South Australia. Anal. W. T. Dalwood. *Ibid.*, 1945, 69, 22.

TABLE IV.

Ratio of Soda to Total Alkalis.

	Albitites and Soda-Syenites. (Table I.)	Soda-Aplites. (Table II.)
I	94·9	98·2
II	91·4	91·6
III	98·1	88·0
IV	98·4	98·1
V	99·3	69·0

In the Encounter Bay region of South Australia Bowes (1954) considers that the albitic rocks formed by assimilation of albite-chlorite-schists and that the country rocks, partly mobilized by the granite, was intruded as a mush containing mechanically derived albite and chlorite. It has been shown above,

however, that albitites and soda aplites are not universally associated with albite-rich country rocks, so although such an origin may be true of this South Australian occurrence, it cannot be accepted as the origin of albitic rocks elsewhere.

Sundius (1926), in describing soda and potash-aplites associated with granites in Sweden, concludes that the aplites were a late differentiate of the granite and that at this stage the magma split into two immiscible fractions giving rise on the one hand to potash aplites and on the other to soda aplites.

Tilley (1919) considered that the Kangaroo Island albitite was a late differentiate of the granite, and this in fact appears to be the case in the Cloncurry area of Queensland, where the albite rocks occur as dykes or small irregular bodies in or near the margin of the granite. Near the Lady Fanny Mine, southeast of Mt. Isa, a potash-pegmatite has been albitized, and Edwards and Baker (1954) have shown that albitization and scapolitization are very widespread in the Cloncurry-Mt. Isa area. If, as Niggli suggests, checker albitite is due to replacement, then late albitization of these small bodies seems a likely explanation of their origin. However, the generally accepted view is that checker albite is a form of twinning, and, furthermore, it would be difficult to account for the highly selective albitization of these small bodies when the surrounding rocks are unaffected. The fact that the felspar is a low temperature type may suggest replacement though it does not preclude a primary origin.

In a recent note (Joplin, Carter and Burnett, 1954), it was suggested that the Precambrian sediments of the Cloncurry area originally contained an appreciable amount of sodium chloride, and it seems possible that the heat of the invading potash granite magma, together with associated fluids, may have brought about the assimilation of sufficient of this salt to give rise to a late soda-rich differentiate of small volume. This idea is put forward very tentatively ; first, because further work is being carried out on the salt content of these sediments, and secondly, because if this explanation of the origin of these rocks is correct then it should be possible to show that it is applicable elsewhere where albitites and soda-aplites occur.

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OF THE

ROYAL SOCIETY
OF NEW SOUTH WALES

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III

1956

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JOURNAL AND PROCEEDINGS

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1956

LIVERSIDGE RESEARCH LECTURE*

RECENT ADVANCES IN THE CHEMISTRY OF THE AROMATIC COMPOUNDS

G. M. BADGER.

Mr. President, Members of the Royal Society, Ladies and Gentlemen,

It is a great privilege and honour to be asked to give the Liversidge Research Lecture and I would like to express my thanks to the Council for giving me this opportunity to discuss the present status of aromatic chemistry, and to indicate some future paths in research. The study of the aromatic compounds has never been seriously neglected, for it has not only posed many problems of academic and theoretical interest but, in addition, many such compounds are of great commercial importance.

It is not inappropriate that the Liversidge Research Lecture should be concerned with this topic in 1956, for this is the 100th anniversary of the discovery of the first synthetic dyestuff, mauveine, by the youthful W. H. Perkin. Until this time the great reservoir of aromatic compounds in coal tar was unexploited : indeed, coal tar was considered a waste product or at the best as a source of pitch. In 1856, Perkin showed that he could convert crude aniline into a commercially valuable product and the whole situation changed. Before long determined efforts were being made to separate the more abundant constituents on a large scale.

Various aromatic compounds had been discovered before this time. Some had been obtained from natural sources, from materials such as gum benzoin ; and naphthalene had been separated from coal tar by Garden as early as 1820. Benzene was first described by Michael Faraday in 1825, but he obtained it from the liquid which separated from a compressed illuminating gas which had been prepared by the pyrolysis of fish oils. It was not until 1849 that C. Mansfield isolated pure benzene from coal tar. At this time fractionating columns had not been invented, and Mansfield had to carry out his distillations in an old-fashioned glass retort, with the thermometer in the liquid. As he isolated not only benzene but also toluene and pseudo-cumene, we can only admire his considerable patience and experimental skill. As he himself said (Mansfield, 1849) :

" It is perhaps the tedium of the methods necessary to effect a separation of mixed hydrocarbons from each other which has deterred experimental chemists from devoting their time to disentangling the oils here treated of : and perhaps to have conducted the innumerable distillations necessary for this purpose in a laboratory imperfectly furnished with gas and other conveniences, would have been a task too laborious to have been persisted in."

Aromatic compounds have often been distinguished from unsaturated aliphatic compounds by their stability and their tendency to undergo substitution rather than addition reactions. Benzene has long been regarded as the simplest of the aromatic compounds, and it was formerly believed to be the parent structure of *all* aromatic compounds. Various heterocyclic analogues of benzene, such as pyridine and thiophen, were said to have " aromatic character ".

H

Such compounds certainly resemble benzene; but "aromatic character" is an uncertain term, for many polycyclic aromatic hydrocarbons differ very markedly from benzene in their general properties.

Anthracene (I), for example, is a rather reactive substance which undergoes many addition reactions. It adds bromine and chlorine at room temperature. It reacts with oxygen in the presence of light to form a photo-oxide, and it readily adds maleic anhydride and other dienophiles in the Diels-Alder reaction. The dark green hydrocarbon, hexacene (II), has even less aromatic character for it is very unstable in light and air, and it reacts almost instantaneously with maleic anhydride. Moreover, although the cancer-producing hydrocarbon, 3 : 4-benzopyrene (III) does not readily undergo addition reactions, it is

I   III

II
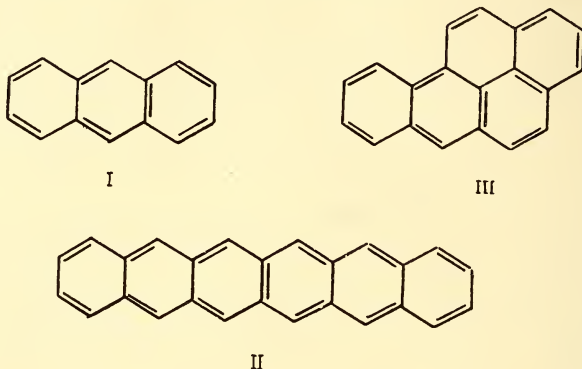
exceptionally reactive in many substitution reactions. It is readily acetoxylated with lead tetra acetate, even at room temperature. It also couples quite readily, even with the moderately reactive p-nitrobenzene diazonium chloride, a reaction which was formerly believed to be confined to phenols, amines and, to a lesser extent, to ethylenic compounds.

In these circumstances it is idle to attempt to define an aromatic compound in terms of its properties or its "character", important though these may be. The only satisfactory way to distinguish an aromatic compound is by reference to its structure.

IV   V   VI   VII
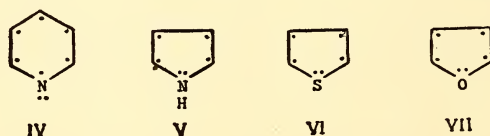
In benzene all the carbon atoms are in the trigonal state of hybridization, and by overlap in the usual way the various orbitals form the carbon-carbon and carbon-hydrogen sigma bonds. The remaining six $2p_z$ orbitals, which are vertical to the plane of the ring, interact laterally to form the π-bonds. This delocalization is the origin of the delocalization or resonance energy of the molecule and is now recognized as the cause of the peculiar stability of the compound.

Heterocyclic analogues of benzene have similar structures. In pyridine the nitrogen atom contributes one electron to the aromatic sextet, and the non-bonding "lone pair" of electrons is responsible for the basic character of the compound. The situation in pyrrole, thiophen and in furan is similar except that the heteroatom contributes two electrons to the aromatic sextet.

This similarity in electronic structure is amply confirmed by the ultra-violet absorption spectra, and particularly by the spectra of the polynuclear aza-hydrocarbons (Badger, Pearce and Pettit, 1951a ; Badger and Seidler, 1954).   Certain differences do exist, of course, but in many cases the resemblance between the spectrum of the hydrocarbon and those of its aza-hydrocarbon analogues is most marked.   The chief electronic difference between the compounds is that the aza-hydrocarbons have two n-electrons not involved in bonding, and these compounds sometimes show a long wave length absorption in hexane solution which can be identified as an n-π^* transition (Badger and Walker, 1956).

Wave length (mμ).
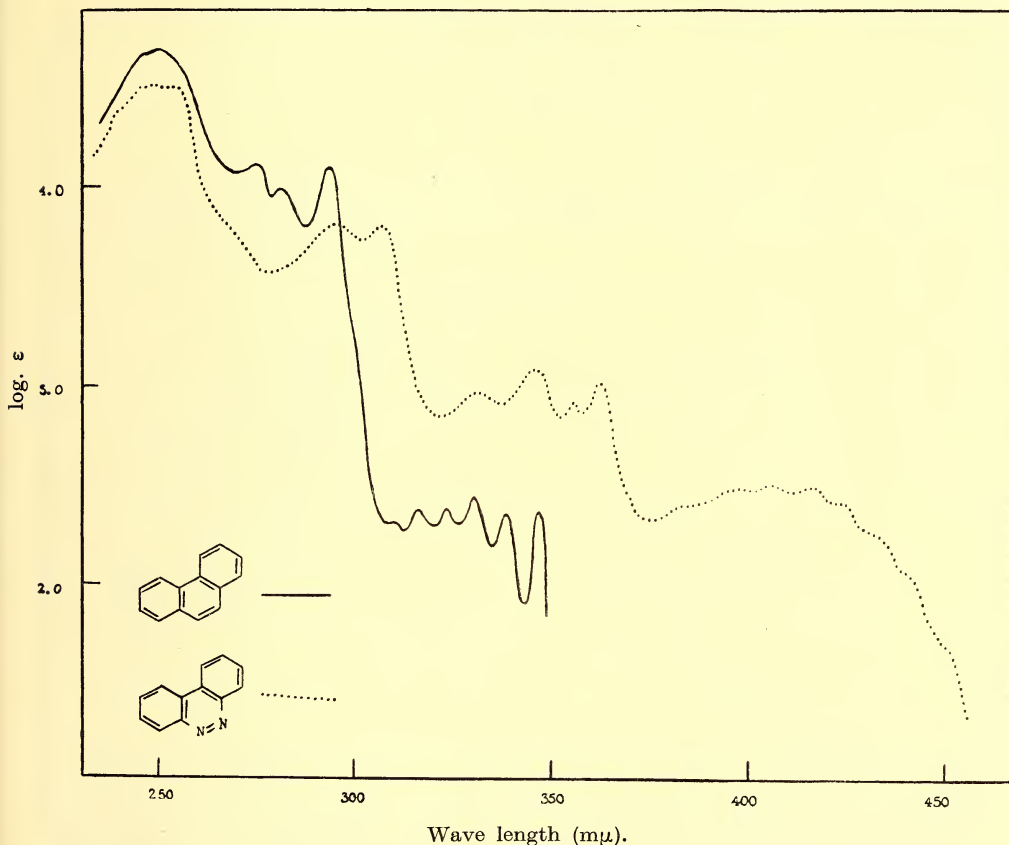
With the 5-membered heterocyclic systems the three main regions of absorption can generally be identified, but the resemblance is less marked particularly in the pyrrole and furan series.   In these cases the electronegativity of the hetero-atom is high so that the 2p orbital is " contracted " relative to the carbon 2p orbitals, and the conjugation is restricted (Badger and Christie, 1956).

The heterocyclic systems also differ from benzene in their stability and in their reactivity, and a few rather less obvious differences become apparent in the polynuclear compounds.

As an illustration of this point it may be noted that 3 : 4-dihydroxy-1 : 2-benzophenazine (VIII) is a deep violet-blue substance quite unlike the

yellow 3 : 4-dimethoxy-1 : 2-benzophenazine (IX). Such differences are not found among benzenoid compounds of the same type and the difference in this case is undoubtedly due to the fact that the dihydroxy-compound (VIII) exists predominantly in the quinonoid form (X) (Badger, Pearce and Pettit, 1951b).

Quinonoid structures of this type are of special interest in heterocyclic chemistry and they are of varying stability. Mild reduction of tetra-azabenzopentaphene gives an unstable red dihydride which probably has the structure (XI). The deep red 13 : 14-dihydro-5 : 8-diazopentaphene (XII) can be prepared synthetically and is sufficiently stable for it to be isolated.

Wave length (mμ).
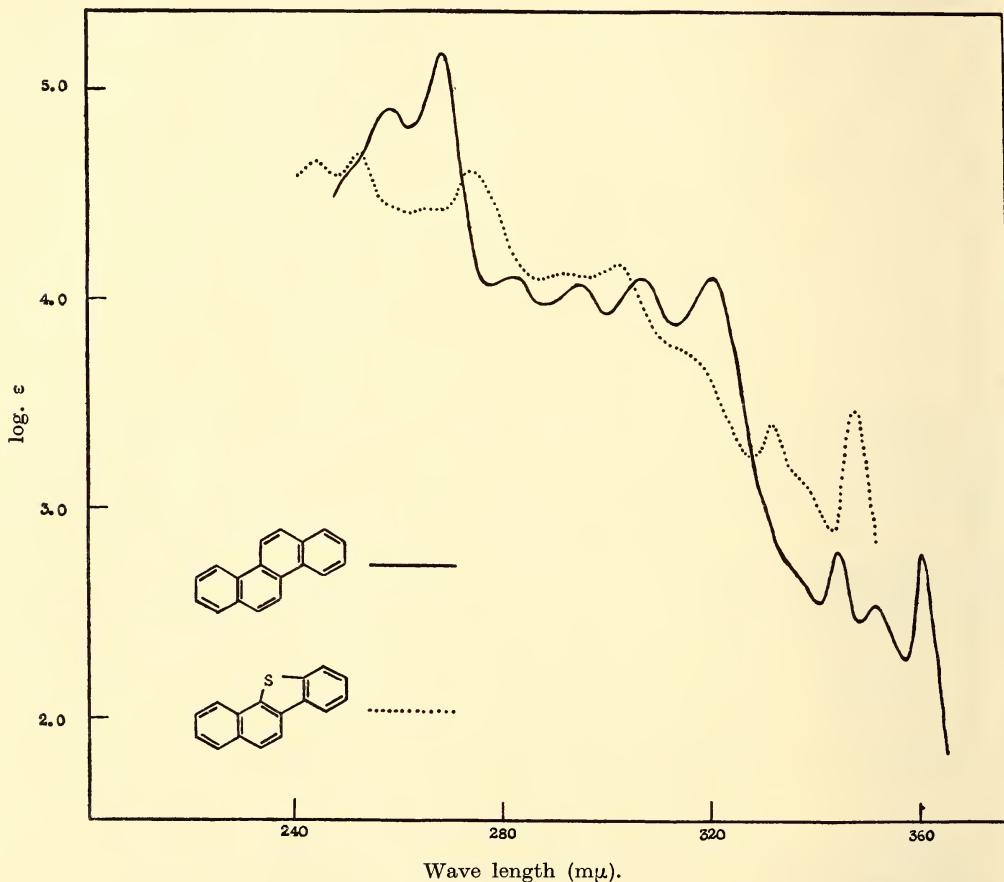
The linear deep blue dihydride (XIII) of tetra-azapentacene, however, is excessively stable and has resisted all attempts to dehydrogenate it to the aromatic state (Badger and Pettit, 1951, 1952a, b).

All these differences are, however, relatively minor in comparison with the overall similarity in electronic structures of the parent ring systems. Pyridine, thiophen, etc. may therefore be regarded as aromatic ring systems and we may define an aromatic compound as *a cyclic compound with a large delocalization or resonance energy, where all the annular atoms take part in a single conjugated system involving an even number of π-electrons.*

This definition leads us to consider whether certain 4-membered, 5-membered, 7-membered, and 8-membered rings may resemble benzene and possess aromatic structure (XIV-XVIII).
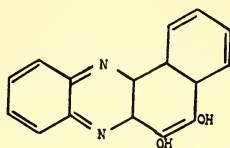
VIII
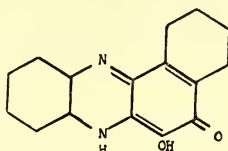
X
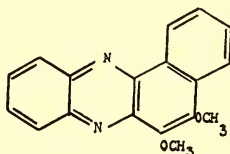
IX

cycloButadiene (XIV) is unknown, having resisted all attempts at synthesis, and in any case the structure would involve a very considerable distortion of the trigonal-hybrid bond angles.
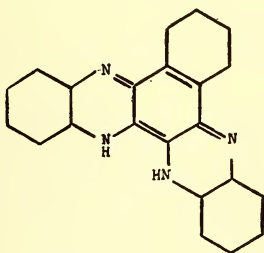
XI
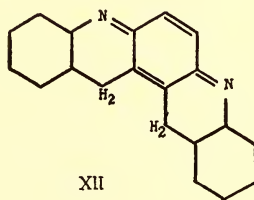
XII
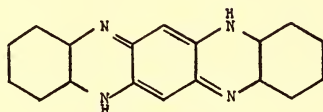
XIII

cycloOctatetræne (XVIII), at the other end of the series, is a well known compound, but all the experimental evidence indicates that the molecule is puckered, and that the bonds approximate to alternate single and double bonds. For aromatic stability and high resonance energy the molecule would have to be planar, in which case the bond angles would be 135° compared to the 120°

XIV   XV   XVI   XVII   XVIII

required for sp² hybridization. It seems that this angular strain is sufficient to counteract the stabilizing influence of resonance.

The 5-membered ring system, cyclopentadiene, is not aromatic, having a resonance energy of only 3 kcals/mole ; but its anion (XV) has a structure closely resembling that of pyrrole and is aromatic. Indeed it is the increased

stability which results which explains why *cyclo*pentadiene forms salts with alakali metals, whereas ordinary saturated carbon atoms do not.

The anionic structure (XV) can also exist in certain substituted *cyclo*-pentadienes, such as diazo*cyclo*pendatadiene. This is a stable red compound quite unlike diazomethane. As Doering and DePuy (1953) have pointed out this compound may be considered as a resonance hybrid of the four contributing structures (XIX-XXII), which explains its aromatic stability.

$$2C_5H_5.MgX + FeX_2 = (C_5H_5)_2Fe + 2MgX_2$$
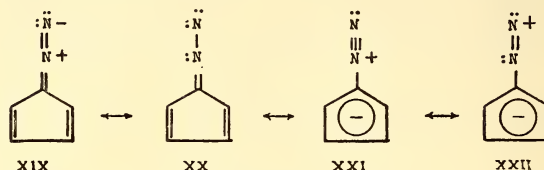
The 5-membered ring system also occurs in ferrocene and related compounds (Pauson, 1955b). Ferrocene was first prepared by the action of ferric chloride on *cyclo*pentadienylmagnesium bromide (Kealy and Pauson, 1951). The ferric chloride was reduced to the ferrous state and reacted further according to the equation :
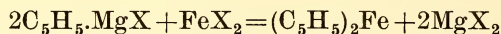
Subsequently it has been shown that ferrocene may also be formed by the direct action of *cyclo*pentadiene on iron at 375°.

It is an extremely interesting compound. It is soluble in all common organic solvents and crystallizes in large orange needles. It is stable to water, to 10% sodium hydroxide, and to boiling concentrated hydrochloric acid. It is volatile above 100° at atmospheric pressure and the vapour is stable to at least 450°. It is not hydrogenated over platinum oxide and it does not react with maleic anhydride. Moreover it undergoes the Friedel-Crafts reaction. With acetyl chloride it gives a red diacetylferrocene, which has been oxidized to ferrocene dicarboxylic acid.

All these properties suggest that ferrocene must have an aromatic structure, and this is supported by other data (Woodward, Rosenblum and Whiting, 1952). For example, the first dissociation constant of the di-acid is very close to that for benzoic acid. Moreover, the infra-red absorption spectrum gives the C-H stretching frequency at 3067 cm⁻¹ (3·26μ) in the region typical for aromatic C-H bonds ; the acetylferrocene gives a carbonyl stretching frequency of 1675 cm⁻¹ (5·97μ) almost identical with that given by acetophenone, 1668 cm⁻¹ (5·93μ).

Many analogous compounds with other metal atoms have also been prepared and these vary considerably in stability. In addition diindenyliron (XXIV) has been prepared. A " sandwich " structure (XXIII) was suggested for ferrocene, and this has been confirmed by X-ray analysis of the crystal structure and by other means ; but the exact fashion in which the two rings are bonded to the iron atom is still under discussion. According to one view the bond is formed between a *d*-orbital of the metal and the π-orbitals of the ring as a whole, all the carbon atoms being bonded equally to the metal atom (Moffitt, 1954). All the transition elements have an available *d*-orbital and it may be noted that ferrocene-like compounds have now been prepared from all of them. On the other hand, the same " sandwich " structure occurs in di*cyclopentadienyl-magnesium* which cannot involve bonding of this type, and the bonding in this case may have considerable ionic character.

According to the alternative theory there is simultaneous bonding of all six π-electrons from *cyclo*pentadiene anions leading to three dative covalent bonds between each ring and the metal (Fischer and Pfab, 1952).   This theory has been adversely criticised ; but it does suggest that similar sandwich-like compounds with unchanged aromatic systems, such as benzene, are possible. When such compounds were looked for they were found, for Fischer has recently reported the preparation of dibenzenechromium (o), and dibenzenemolybdenum (o) (Fischer, 1956).

In addition to these compounds there is also the group of substances in which only one *cyclo*pentadienyl ring is linked to a metal atom to which other groups such as CO are attached.   A particularly interesting example is di*cyclo*pentadienyldiirontetracarbonyl, the structure of which has been recently established (Hallam, Mills and Pauson, 1955).

Further research is clearly necessary to determine the nature of the metal-carbon bonds in all these compounds, and especially to determine the degree of ionic character in the analogous compounds involving other metal atoms. A comparison of the strengths of carboxylic acids derived from ferrocene analogues involving different metals would be useful.   A study of the exchange reaction using the radioactive isotope corresponding to the metal concerned (e.g. ^{60}Co with di*cyclo*pentadienylcobalt) might also give information of value.

XXVI   XXVII   XXVIII
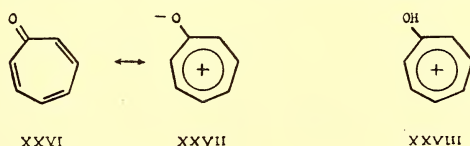
This brings us to the 7-membered ring system.   The parent compound, *cyclo*heptatriene, has a small resonance energy and is clearly aliphatic.   The *cation*, however, has six π-electrons and as the distortion from the sp² valency angle of 120° is small, this system (XVII) must be said to have an aromatic structure.   The *cyclo*heptatrienylium (or tropylium) ion has been prepared by Doering and Knox (1954 ;   see also Dewar and Pettit, 1955) who found it to be a stable cation.   Once again the C-H stretching frequency occurs in the infra-red at 3020 cm⁻¹ (3·32μ), a figure which is similar to that for other aromatic compounds.

The same ring system occurs in tropone and in tropolone (Pauson, 1955). Tropone may be given the structure (XXVI), but it is better represented as the hybrid of this structure together with (XXVII) in which the positive charge is equally shared by all the annular carbon atoms.   This latter structure emphasises its relationship to the tropylium ion (XVII), and it also explains the basicity of the compound, for tropone readily forms stable salts with acids to give the cation (XXVIII).

The hydroxy-derivative of tropone, which is known as tropolone, has been very extensively studied (Dewar, 1945 ;   Johnson, 1951).   It is best regarded as a resonance hybrid of the three structures (XXIX-XXXI), but it undergoes very ready tautomerism to the resonance hybrid represented by structures (XXXII-XXXIV).

Tropolone shows all the properties of an aromatic substance.   It has a resonance energy of 29 kcal./mole.   The ring system is a regular heptagon with an average C-C bond length of 1·40 Å (Robertson, 1951), and the carbon-hydrogen stretching vibration occurs in the infra-red spectrum at 3050 and 3015 cm⁻¹ in agreement with other aromatic compounds (Koch, 1951).   It undergoes a number of substitution reactions : it can be nitrated, nitrosated and brominated ;   and it couples with diazonium salts.

It is also of some interest that this stable aromatic system has been identified in a number of natural products : in stipitatic acid ; in puberulic acid ; in purpurogallin ; in the thujaplicins ; and in colchicine (Pauson, 1955).

These recent advances in the chemistry of non-benzoid aromatic hydrocarbons are interesting and important ; but we cannot neglect the benzenoid compounds, which still pose many problems. Many aromatic compounds can be produced from petroleum by various pyrolytic processes, but the main source is still coal tar, from which several hundred substances have already been isolated.

XXIX   XXX   XXXI

XXXII   XXXIII   XXXIV
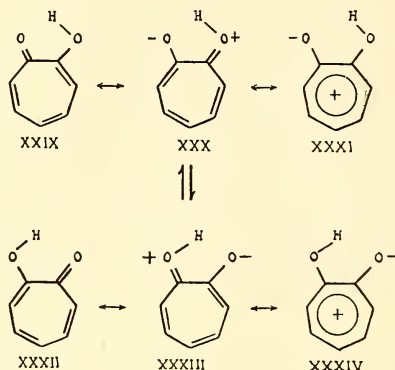
In spite of the great volume of work which has been carried out in this field it is surprising how little we really know about the mode of formation of the aromatic constituents of coal tar. The complete system is exceptionally complex, and it is necessary to consider several isolated aspects of the problem before any understanding can be reached.

When coal is heated in the absence of air it begins to decompose at about 300°. Between 300–450° it gives a " primary " tar which consists mainly of paraffins, *cyclo*paraffins, olefins and phenols. This " primary " tar is believed to be formed by splitting off various fragments and side chains from the main coal structure, and it is noteworthy that it contains only small quantities of aromatic hydrocarbons (Vahrman, 1952).

Tars from Durham Holmside Coal.

Carbonization Temperature.	Carcinogenic Activity.
450°	+
560°	+++
1250°	++++

In ordinary gas-works or coke-oven practice, however, much higher temperatures (of the order of 900–1200°) are involved and the " primary " tar is converted into a " secondary " tar. This secondary tar, which is the normal " coal tar ", contains many different aromatic ring systems, and the problem is to determine how each is formed. It is only at these higher temperatures that compounds such as anthracene and the higher polycyclic aromatic hydrocarbons are formed. In this connection it is significant that tar obtained at 450° is only very weakly cancer-producing, and that the cancer-producing constituent (presumably 3 : 4-benzopyrene) is largely formed between 450° and 560°, there being only a slight increase in the amount formed between 560° and 1250° (Kennaway, 1925).

Dehydrogenation and cyclodehydrogenation.

The cyclization of paraffin hydrocarbons to aromatics was first described by Norton and Andrews in 1886, who obtained a small amount of benzene by passing hexane through a hot tube. In recent years it has been shown that the process is catalyzed by various oxides, which may be supported on alumina or used in the pure state, and it has now been rather extensively studied (Moldawskii and Kamuscher, 1936). Under these catalytic conditions, at temperatures of 450–600°, paraffins and olefins containing six or more carbon atoms are converted into aromatic compounds. It seems that three distinct stages are involved : the dehydrogenation of the paraffin to the corresponding olefin ; the cycloisomerism of the olefin to a hexahydrobenzene ; and thirdly the dehydrogenation to the aromatic hydrocarbons (Steiner, 1950). (Of course if the initial material is a suitable olefin or cycloparaffin, only one or two of the stages may be required). In this way *n*-hexane and hex-1-ene give benzene ; *n*-heptane and 2-methylhexane give toluene ; and *n*-octane gives *o*-xylene together with ethylbenzene and some *m*- and *p*-xylene.
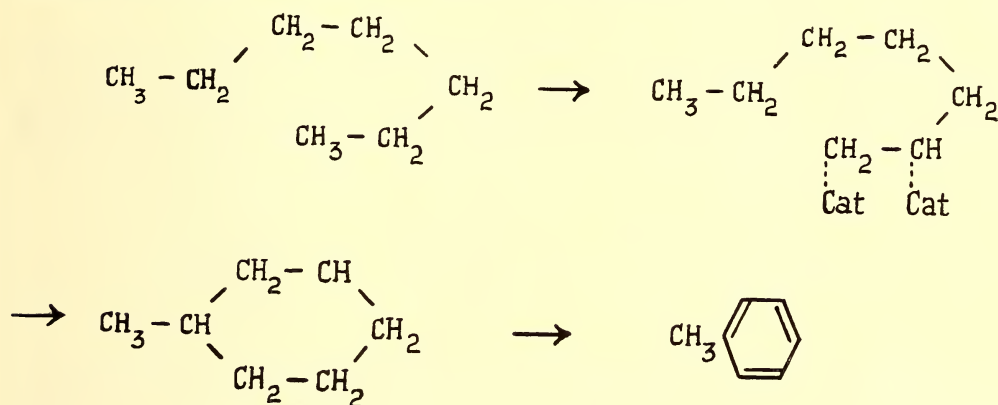
Reactions of this type must clearly occur at the high temperatures involved in the coal gas-coal tar process, and the surface of the coke may well be of considerable importance. Many of the simple benzenoid compounds may therefore be formed in this way.

It is possible that similar cyclization-dehydrogenation reactions may also account for some of the polycyclic aromatic products. Several reactions of this type have been studied experimentally, and the following examples serve to indicate the type of cyclization which can occur (Hansch, 1953).

n-Butylbenzene has been converted into naphthalene in quite high yield by heating with chromium oxide catalyst at 500° ; and naphthalene is also obtained from *o*-diethylbenzene with a zinc oxide-calcium oxide on alumina catalyst at 600°. *Cyclo*pentene also gives naphthalene.
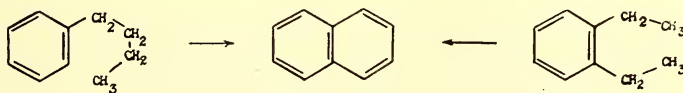
Anthracene has been formed by the pyrolysis of toluene, and it can be obtained in quite reasonable quantity by heating *o*-benzyltoluene with lead oxide.
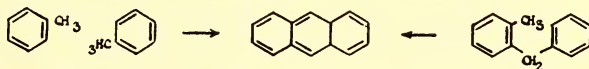
Similarly the pyrolysis of 1-benzyl-2-methylnaphthalene yields 1 : 2-benzanthracene.

Using processes of this type it is possible to account for the formation of a great many substances from simple paraffins. *n*-Decane is converted into many different aromatic compounds by heating on a chromia-alumina catalyst and these can all be accounted for by a combination of cyclization and cracking reactions (Hansch, 1953).

Aromatic ring systems are relatively stable even at high temperatures, but they do condense with elimination of hydrogen to form more complex ring systems and this reaction must also occur during coal carbonization processes at the high temperatures involved.

Benzene can be converted to diphenyl by passage through a red hot tube or by passing over a red hot wire. 1 : 2-Diphenylbenzene has also been reported, together with the *m*- and *p*-isomers ; and triphenylene has been isolated in small amount. A series of condensations leading to triphenylene and similar compounds would therefore seem not unreasonable (Kinney and DelBel, 1954).
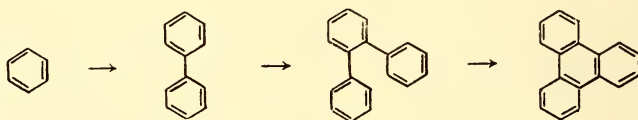
On a somewhat similar scale, the following condensation of compounds which occur in low temperature tar to compounds which occur in high temperature tar, would also seem to be important (Mantel and Hansen, 1953).
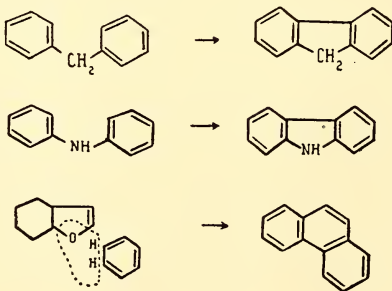
An especially interesting laboratory dehydrogenation of this type (which however was brought about with palladium) has been reported by Baker *et alii* (1951) and may serve as a model for the formation of pyrene (see below).
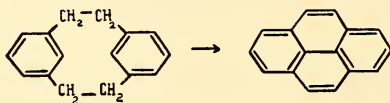
Diene synthesis.

All the reactions mentioned in the preceding section involved cyclization or condensations such that the end product has the same number of carbon atoms as the starting material. As reactions of this type are catalysed by a variety of substances it seems likely that it is predominantly a surface reaction and that there is little or no contribution from vapour phase reaction.

Nevertheless reactions do seem to occur in the vapour phase as exemplified by the Weizmann process for the formation of aromatics by the thermal cracking of petroleum in empty or packed tubes at 630–680° (Weizmann *et alii*, 1951). Under these conditions it has been suggested that the fundamental process must involve an initial cracking of the material to small molecules such as acetylene and butadiene and that re-synthesis occurs by diene addition. The following examples indicate the nature of the synthesis, and there is every reason to expect that reactions of this type may also be of significance in the formation of coal tar.
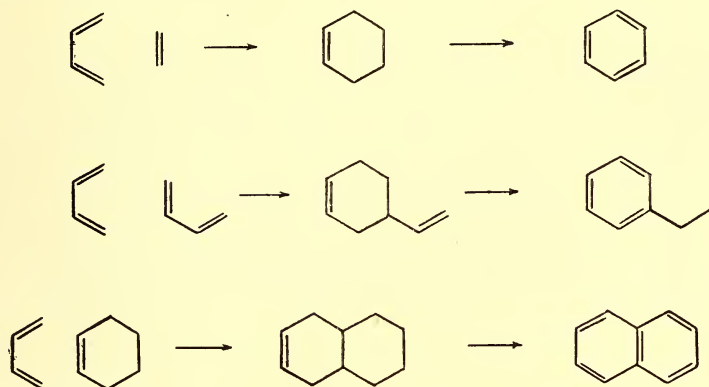
It is significant that the Weizmann process leads to relatively larger amounts of styrene and ethylbenzene in the " xylene " fraction, whereas the catalytic cyclization of *n*-octane mentioned previously leads mainly to *o*-xylene, although ethylbenzene is also formed in small amount.

Similar diene syntheses have also been postulated for the formation of polycyclic compounds, as exemplified by the following, but it must be admitted that the evidence is scanty.
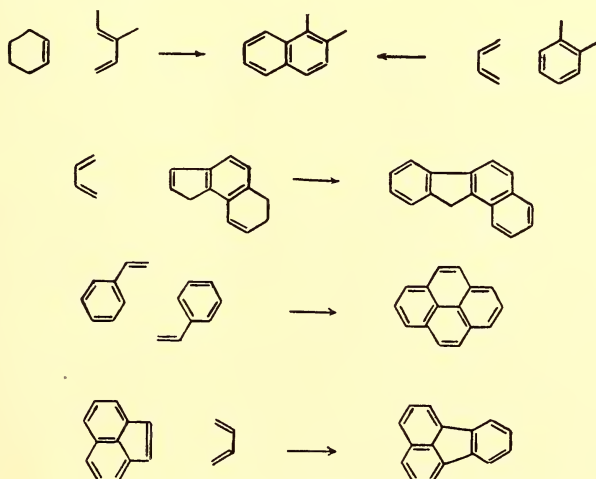
Some experiments on the polymerization of acetylene by pyrolysis have also been reported and, indeed, the original experiments of Berthelot (1866) in this field are of great importance in the history of organic chemistry. It is a pity that some of these have not been repeated in recent years as we now have available many new experimental techniques. Nevertheless Berthelot did obtain benzene, styrene, and some other compounds. Zelinsky did repeat the experiment under slightly modified conditions in 1923, and he identified benzene, toluene, *p*-xylene, styrene, indene, naphthalene, fluorene and anthracene among the products. *cyclo*Octatetraene has since been discovered among the products of the thermal polymerization of acetylene, but it is produced in much larger amount by the Reppe process which involves the use of a catalyst.

Unfortunately no attempt has been made to identify compounds in the higher boiling fractions and these may well be important for Kennaway (1925) has found that the tar produced by the pyrolysis of acetylene is cancer-producing, and the presence of 3 : 4-benzopyrene may be inferred from the fluorescence spectrum of the tar.

3 : 4-Benzopyrene has a characteristic fluorescence spectrum which enables it to be identified in very complex mixtures. Chromatography and absorption spectroscopy have also been used for this purpose and this cancer-producing hydrocarbon has now been identified in coal tar, in the atmospheric dust of cities, in domestic soot, in the soot in the chimney of a smoked sausage factory, in processed rubber, in commercial carbon black and in cigarette smoke (Cook *et alii*, 1933 ; Waller, 1952 ; Goulden and Tipler, 1949 ; Falk *et alii*, 1951 ; Falk *et alii*, 1952 ; Cooper, Lindsey and Waller, 1954). Its mode of formation is therefore of great importance. As a working hypothesis the following scheme may be suggested for the pyrolytic formation of 3 : 4-benzopyrene.
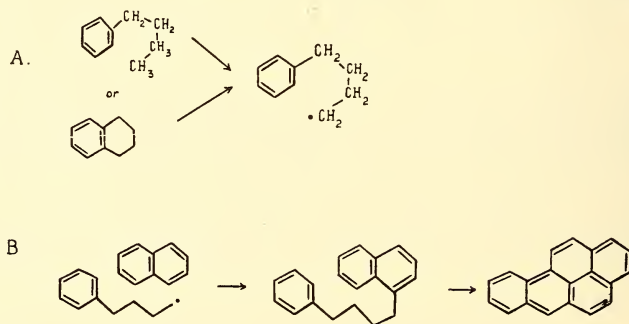
A somewhat similar scheme has been suggested for the formation of benzo-pyrene by the action of aluminium chloride on tetralin. In view of its widespread occurrence in human surroundings the mode of formation of this very powerful carcinogen is of very great importance, and work is being directed towards the solution of this problem.

With regard to the general problem of the formation of aromatics, we may safely say that the pyrolytic processes are exceptionally complex. There is little doubt that reactions similar to all those which I have described occur, at least to some extent, in the formation of coal tar, and possibly in the formation of the tarry matter in soot and similar materials ; but little is known about the relative importance of these processes.

Earlier in this lecture I indicated that aromatic chemistry has always attracted the attention of chemists. I have tried to tell you about some of the problems which have been studied in recent years, and some which are at present under investigation. I hope you will agree that there are many extremely interesting problems still awaiting solution.

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OBSERVATIONS ON MT. GIBRALTAR, N.S.W.

By Robert Stevens.

With three Text-figures.

I. Introduction.

Mt. Gibraltar is a prominent and well known landmark in the Southern Highlands of New South Wales, overlooking both Mittagong and Bowral, and standing immediately to the east of the Main Southern Railway between the two towns, some eighty miles south-south-west of Sydney. The area is close to the south-western margin of the Cumberland Basin, a region of essentially conformable Permian and Triassic sedimentation which has suffered only local subsequent deformations. The broad geological picture is one of undisturbed Permian sediments resting with angular unconformity on a basement of older and middle Paleozoic folded sediments and intrusive granitic rocks, and being conformably overlain by Triassic sediments of no great thickness. The Permian sediments are divided into the Shoalhaven Group at the base (a marine sandstone sequence perhaps 1,000 ft. thick in this vicinity), and the Illawarra Coal Measures at the top (an alternating sandstone-shale-coal sequence probably no more than 150 to 200 ft. thick). The Triassic is represented in this area by the Hawkesbury Sandstone (about 600 ft. of very uniform, thickly bedded quartz sandstone), followed by the Wianamatta Group of shales and sandstones no more than 180 ft. thick around Mittagong and Bowral. Early in Tertiary times a series of basic and intermediate igneous rocks were intruded into the Permian and Triassic strata, and Mt. Gibraltar is one such intermediate intrusive mass. Following the emplacement of these bodies came a period of fairly active erosion which stripped many of the intrusives of their cover, after which, in later Tertiary time, came another period of volcanic activity during which basaltic lavas were poured out over the eroded surface, sometimes partly covering the intrusive bodies, and sometimes flowing around them as though they were islands. Further erosion has reduced these conditions to their present state, removing much of the extrusive basalt in the process.

The Gib, as Mt. Gibraltar is commonly known, has found favour in the eyes of a number of earlier workers, most of whom have considered it to be the main expression of tertiary volcanic activity in the district, but who, with one notable exception, have told us very little concerning its more detailed characters. As the title of this paper indicates, the present work will do little to alleviate this situation, but will include several newly recorded observations with respect to its petrography and structure.

The Gib has been quarried for many years, and the rock obtained from it may be found gracing the fronts of several city buildings, monuments and other edifices. It is surprising, then, that it has not received greater geological attention in the past, not only from an economic point of view, but also as a matter of scientific interest. Jaquet (1901) mentions the Gib in his report on the iron ore deposits of the district, at which time the rock was quite widely known as the " Bowral Trachyte ". Taylor and Mawson (1903) considered

the Gib rock to be a syenite allied to bostonite, and divided it into a marginal leucocratic phase and an internal melanocratic phase. It is apparent from a comparison of their petrographic description (p. 317) with recently examined specimens that the rock with which they dealt was considerably weathered, so that their chemical analyses of the melanocratic and leucocratic phases must be regarded with caution. Taylor and Mawson also state that " the Gib represents the denuded plug of an old volcano" (p. 317), and cite as proof of the fact that " only a few hundred feet of shales . . . . could have remained undisturbed to check the immense volcanic energy of so large a mass of molten magma ", thus indicating that it must have broken through the surface. More will be said to this point later ; at present it is sufficient to say that available evidence does not indicate any extrusive activity in association with the Gib, and that the thin layer of overlying sediments may well have been sufficient to restrain any plug-forming tendencies.

The exception referred to above in connection with the literature of Mt. Gibraltar is the excellent work of Mawson (1906) presenting the results of his study of the pegmatite veins in the Gib rock. With respect to the earlier work (i.e., Taylor and Mawson, 1903) he states that " more detailed work has revealed that originally the whole mass of the Gibraltar syenite was fairly uniform in character, and that the ' leucocratic ' variety owes its light colour to extreme carbonation of the ferriferous minerals " (p. 580). Mawson also found that the rock was not a bostonitic type, but, as he calls it, an aegirine syenite consisting of feldspar and pyroxene as the essential components. The pyroxene he determined as aegirine and aegirineaugite.

Browne (1933) briefly describes the Gib as a denuded laccolith of micro-syenite whose intrusion has tilted the Hawkesbury Sandstone to north, east and south. The rock itself he describes as an aegirine microsyenite with pneumatically altered phases, and intersected by " narrow segregation veins of pegmatitic aspect." Essentially the same comments are to be found in David (1950), this part of which is probably based on Browne's earlier work.

Booth (1936) carried out a detailed magnetic survey on the Gib and drew up an accurate map of the intrusion. He too considered the Gib to be denuded laccolith of fine-grained syenite, and his magnetic survey indicated to him that " . . . . if minor irregularities be neglected, the Gib intrusion is essentially of the nature of an asymmetrical laccolith having its greatest thickness, and probably an elongated feeding channel, to its west, thinning rapidly to north and south, and having its greatest extension (dipping down) to the east." (p. 47). The remark in parenthesis is inserted by the author for added clarity. Booth's conclusions are quoted at some length because, from an inspection of his geophysical results and from personal observations in the field, the present writer is in agreement with him.

II. PETROGRAPHY.

The writer's own observations on Mt. Gibraltar show that the rock is a medium-grained microsyenite consisting of potash feldspar, pyroxene, rare amphibole, chlorite, carbonate and iron ore as the main constituents. The feldspar, amounting to some 70% of the rock, forms tabular to subhedral crystals averaging about 1 mm. across. It is a normal orthoclase carrying occasional inclusions of pyroxene, iron ore and acicular apatite. The pyroxene is of three fairly distinct types, though a continuous compositional gradation seems to exist between them. Thus, there is a slightly yellowish-green augite presumably containing a small proportion of the aegirine molecule, a green aegirineaugite, and a deep green aegirine. Augite and aegirineaugite occur as subhedral to euhedral crystals sometimes included in feldspar, and are thus of early

crystallization. The aegirineaugite grades, both in composition and mode of occurrence, into strongly coloured aegirine interstitial to the feldspar, and which is thus of later crystallization. The aegirine is strongly pleochroic with X=deep blue-green, Y=deep green, and Z=green, and may at times be difficult to distinguish from a green sodic amphibole (arfvedsonite) occasionally found in the microsyenite, but very abundant in the pegmatite. All pyroxenes together constitute about 10 to 15 % of the rock, aegirineaugite being the most abundant. A yellowish chlorite (2 %) occurs as roughly equidimensional areas up to 1 mm. across throughout the rock and is commonly included in the feldspar. In other cases pyroxene is moulded on the chloritic bodies, so that the chlorite must be regarded as being pseudomorphous after an original mineral of very early crystallization. Granular magnetite is commonly included in the chlorite, and in some instances there is also abundant associated (?) sideritic carbonate. Interstitial material of the rock consists of deep brown masses of fibrous to spherulitic chlorite, in many cases with associated (?) siderite. Where carbonate is present it usually occupies the central part of the interstitial fillings. Quartz has not been found in the rock, other than in the pegmatite veins and occasional vugh-fillings.

The rock has been classified as an aegrine microsyenite by Browne (1933) and David (1950), but it is felt that the use of the prefix " *aegirine-* " alone gives rise to a somewhat misleading idea of the composition of the rock. In simple terms, the rock is an alkaline microsyenite, and not strictly a sodic one as may be supposed from the character of the constituent pyroxenes. While the pyroxenes themselves are certainly in large part of sodic composition, it must be remembered that the very abundant feldspar is predominantly potassic. It is, therefore, suggested that the rock be regarded as an *aegirineaugite micro-syenite* since, if full justice is done to the complete array of pyroxenes, the name " ægirine-ægirineaugite-augite-microsyenite " would be a little cumbersome. Ægirineaugite, being the most abundant pyroxene, is therefore a more satisfactory prefix.

The microsyenite is transected by numerous, narrow veins of pegmatitic character. These have been thoroughly described and elaborately classified by Mawson (1906), and little more need be said concerning them here. The interested reader is referred to Mawson's paper for further details. Mawson identifies the pyroxene of the pegmatite as ægirine and the amphibole as arfvedsonite, rarely passing into a riebeckitic variety. Specimens more recently collected by Mr. W. B. Dallwitz of the Bureau of Mineral Resources, Canberra, and kindly lent to the author for examination, show that arfvedsonite and deep blue riebeckite are present in almost equal proportions. Thus, it would appear that with deeper penetration of the quarries (from which the pegmatite is best collected) into the mass, fresher rock has been exposed which is either intrinsically richer in riebeckite, or in which this amphibole species has not been removed by alteration. The feldspar of the pegmatitic veins differs from that of the microsyenite in that it is not orthoclase, but perfectly euhedral sanidine with an optic angle very close to zero. The presence of sanidine in the later pegmatite, contrasted with the orthoclase of the earlier host rock poses an interesting problem in the pressure-temperature relations between these two feldspar species, and it is hoped that this will form the subject of a forthcoming research project. It is also interesting to note that, in the specimens examined by the writer, the bulk composition of the pegmatite approaches that of an exceedingly alkaline granite which would indeed have given rise to a spectacular rock had segregation continued to the stage of the formation of a separate intrusive body of this material.

In many places the microsyenite and associated pegmatites have been highly altered. Under such circumstances the feldspar is kaolinized and the

pyroxene firstly uralitized, and later converted to an aggregate of carbonate and chlorite. The amphiboles have been readily subject to carbonation, during which process abundant hematite and other hydrated iron oxides have also formed from them. Fluorite has also been observed in association with the carbonate in some cases. These processes of alteration are almost certainly of deuteric nature, brought about by circulating late-magmatic fluids, largely aqueous, containing abundant carbon dioxide, flourine, and other volatiles.

III. STRUCTURE.

The form of the Mt. Gibraltar intrusive body is an interesting one. As indicated above, it has been variously described as a plug, a laccolith, and an asymmetrical laccolith. The author's conclusion is that the Gib is a contemporaneously faulted asymmetrical laccolith. It is abundantly apparent that the emplacement of the microsyenite has resulted in a marked displacement of the country rocks, so that the overlying roof-rock of Hawkesbury Sandstone has been arched up into a short anticlinal structure plunging eastwards, with its limbs rapidly flattening out to the north and south. To the west the intrusive rock terminates abruptly in an almost vertical cliff-face ending at a considerably lower level in talus-covered Wianamatta shales. Now, to the east of the highest part of the igneous mass it is quite clear that the Hawkesbury Sandstone has been arched up over the intrusion, and if this was of the nature of simple doming, then the sandstone should also plunge down again on the western side, there forming the country rock as on other sides. But it does not, and we find instead the stratigraphically higher Winanmatta shales abutting against the western face of the intrusive mass, where they retain a more or less undisturbed attitude.

Stated more specifically, the writer has come to the conclusion that the western face of the microsyenite is cut off by a vertical fault or system of faults of some magnitude, having a general arcuate trend convex to the west, and with an average or mean strike a little west of north. The arcuate trend of the fault is somewhat disturbed by a re-entrant block of Wianamatta shales just to the east of the railway tunnel. The general relationships of the micro-syenite to the surrounding country rocks are shown in text-fig. 1, modified from Booth's map of 1936.

Field observations show that on its western side the intrusive rock comes into contact with Wianamatta shale at an altitude of about 2,250 ft., while at its eastern contact, some half a mile distant, it is overlain by Hawkesbury Sandstone at an elevation of some 2,650 ft. The highest point of the intrusive mass, Gibraltar Trig, stands at an altitude of 2,830 ft., so that the igneous rock projects roughly 600 ft. above the lower sedimentary rocks to the west (not 1,000 ft. as Taylor and Mawson have estimated). These features are illustrated, strictly diagrammatically, in text-fig. 2, from which it is evident that the Hawkesbury Sandstone must have extended over the top of the mass to be cut off on the western side by the proposed fault.

It is highly probable that the formation of the initial laccolithic body commenced at or near the base of the Hawkesbury Sandstone (an inference drawn from the fact that other major intrusive bodies of the district, to be described in a later paper, have been emplaced either at the base of the Hawkesbury or at its top. That the Gib is largely overlain by Hawkesbury Sandstone in its eastern extension would show that it most likely belongs to that group intruded at the base of this sandstone unit.) If this is so, the overlying strata consisted of some 600 ft. of Hawkesbury Sandstone plus at least 180 ft. of Wianamatta shales, ie., initial intrusion took place under an original cover of at least 780 ft. of Triassic strata. It has been shown that

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faulting of the laccolith has uplifted the Hawkesbury Sandstone east of the fault about 600 ft. above the present Wianamatta surface to the west of the fault. If we assume that the sandstone over the Gib is in fact basal Hawkesbury Sandstone, and if we further assume that the present Wianamatta surface to the west of the Gib is the same as that at the time of faulting, then the vertical displacement of the fault is of the order of 1,380 ft. and the magmatic material must then have reached the surface along the fault line. However, it is improbable that the present thickness of Wianamatta is the same as that at the
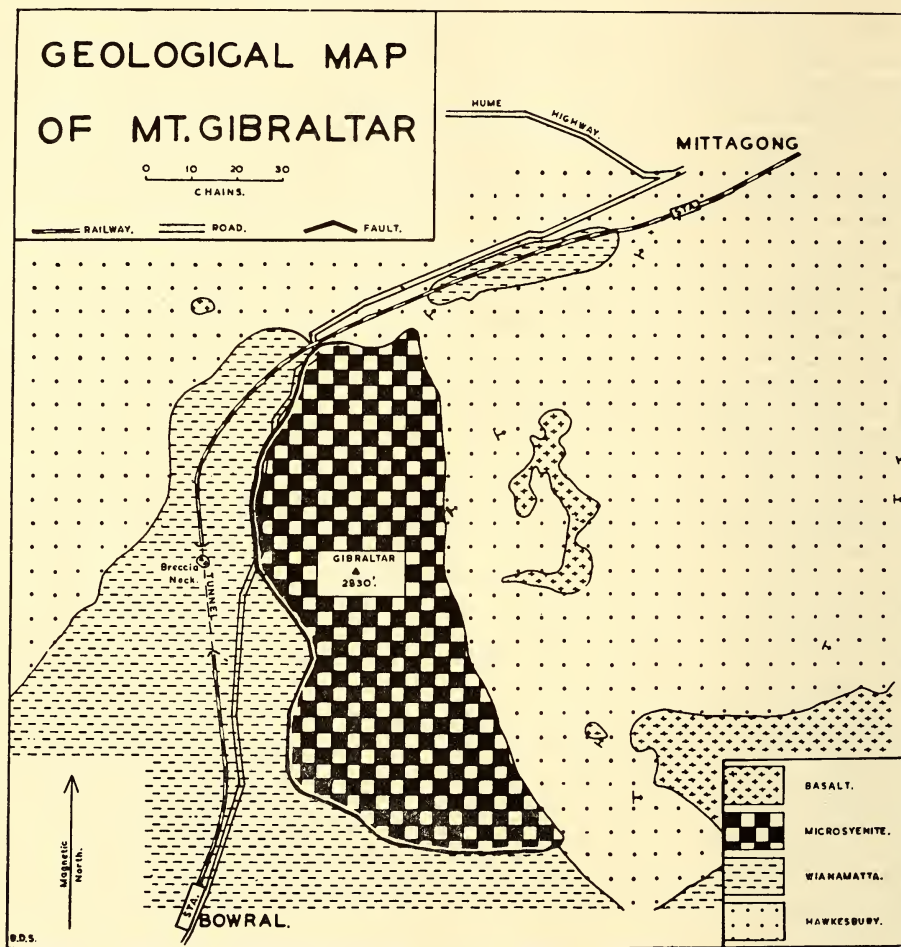
Text-figure 1.

time of emplacement of the Gib rock, for it has been shown elsewhere (Stevens, 1954, p. 8) that there was a period of considerable erosion between the emplacement of the intermediate intrusives and the extrusion of the later Tertiary basalts. Thus, an unknown thickness of Wianamatta was removed during this interval. It is also apparent that there has been further erosion of the land-surface in more recent times, so that, considering these two points, it is evident that the present maximum thickness of 180 ft. of rocks of the Wianamatta Group does not represent their former thickness at the time of intrusion of the Gib rock. Nevertheless, it is apparent that the igneous magma must have
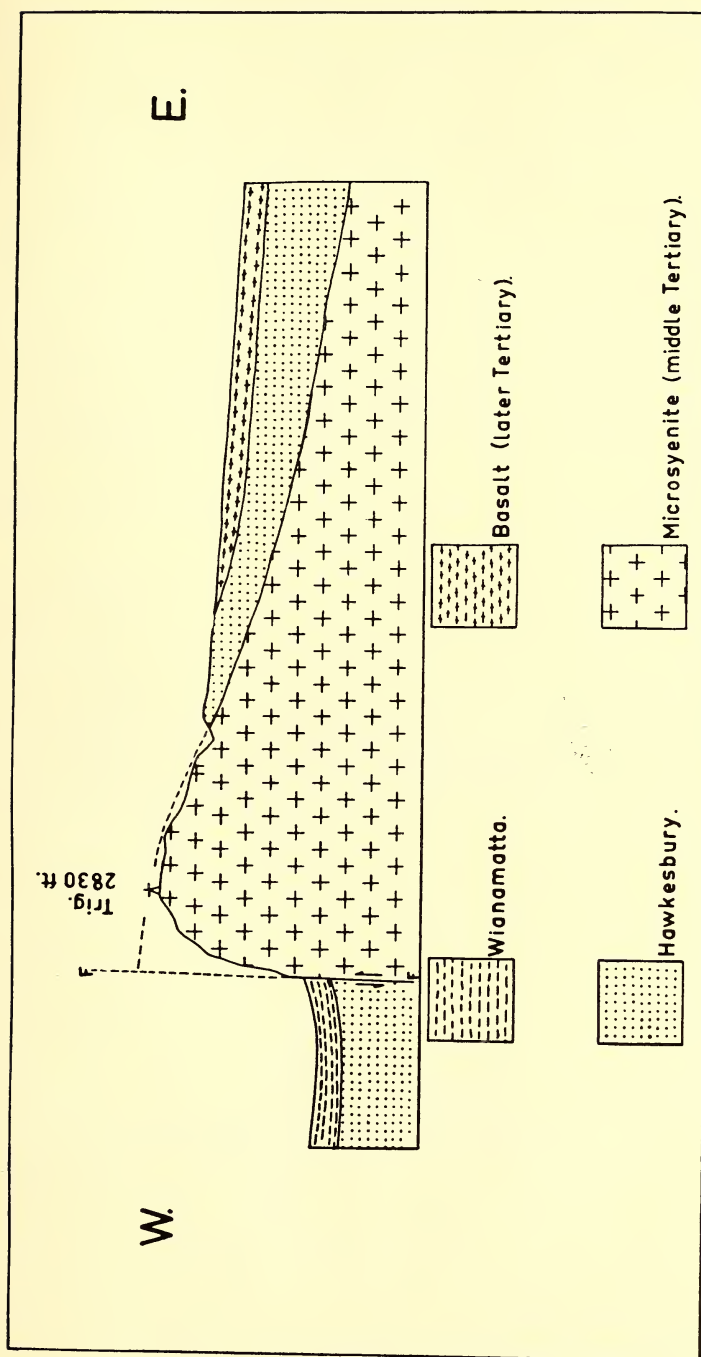
Text-figure 2.

reached the surface unless the post-Hawkesbury Sandstone sequence was at least 600 ft. thicker than it is at present. That such a thickness of post-Hawkesbury, pre-Tertiary sediments could have been present is very difficult to reconcile with the known stratigraphy of eastern N.S.W. It is recognized that the Wianamatta Group reaches a maximum thickness of some 800 ft. (Lovering, 1954, p. 187) in the central parts of the Sydney Basin, and it is generally considered that it thins out rapidly towards the edges of the basin. However, an inspection of Lovering's map (his map 6, p. 177) shows that only the lowermost formation (Ashfield Shale) of the Wianamatta Group is represented in the Mittagong-Bowral district. Were the successively higher formations also originally present? If the original Wianamatta sedimentary sequence was of the order of 800 ft. thick in this area, then it is apparent that the igneous magma of Mt. Gibraltar mass need not have reached the surface. If, on the other hand, the original Wianamatta sequence was less than 600 ft. thick, then the magma must necessarily have poured out over the surface, *provided* there were no sediments of later age than the Wianamatta present, and under such circumstances a considerable volume of trachytic lava must have been extruded. As is well known, however, there is no evidence of either a greater thickness of Wianamatta or other pre-Tertiary sediments, or of any significant extrusive volcanic activity from a source of this or similar composition. Thus there remains the unsolved problem : was the Wianamatta in this area originally more than 780 ft. thick, or was a considerable volume of trachytic lava extruded at the surface from the Mt. Gibraltar intrusive body?

The microsyenite is entirely massive, without any indication of fluidal textures which might be expected if the intrusive body was feeding an extensive system of flows at the surface. Neither has any extrusive lava of intermediate composition been found in this or surrounding districts. There is, indeed, a thin, very limited intercalation of vitric tuff in the sub-basaltic Tertiary sediments at Mt. Jellore, but these sediments are very highly ferruginized and it is impossible to determine whether the tuff is basic or intermediate in composition. It is, in any case, of very insignificant amount. There are, therefore, many fundamental questions concerning the complete character of the intrusion and the stratigraphic conditions at the time of emplacement which cannot be answered from the information at present available.

An inspection of Booth's map of magnetic anomalies shows that there is some geophysical support for the postulated form of the intrusion, in that there is a particularly steep magnetic gradient across its western contact, dropping from 2,000 γ to a general level of about 500 γ over a westerly distance of 15 to 20 chains, indicating a sharp discontinuity in this vicinity. A conclusion not specifically drawn by Booth is that the distribution of maximum anomalies would suggest that the " elongated feeding channel ", if it does in fact exist, probably strikes about 10° west of north, this also being very close to the mean strike of the proposed arcuate western boundary fault.

Thus, the Gib is a faulted asymmetrical laccolith and text-fig. 3 has been prepared to illustrate the mode of evolution of such an intrusive body. In the first stage it is proposed that emplacement of the intrusive rock began with the formation of a small laccolith at or near the base of the Hawkesbury Sandstone, accompanied by a gentle up-arching of the overlying sediments. In the second stage continued intrusion resulted in further flexing of the roof-rock until the brittle sandstone immediately above the expanding laccolith reached the limit of its flexibility, whereupon it fractured at the point of greatest curvature (and stress), and expansion of the laccolith continued by an upward faulting of the roof-rock on one side of this fracture. Thus. it might be expected, as certainly seems to have been the case, that the arched structure would fail directly above the feeding channel and that, with continued injection of
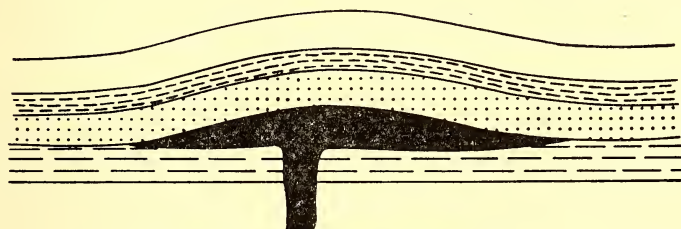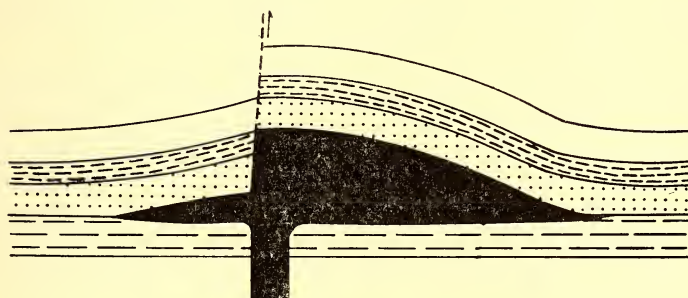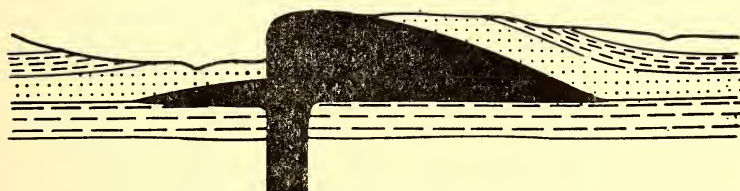
Text-figure 3.

magmatic material, one side of the now faulted dome would rise like a trapdoor to accommodate the ever-increasing volume of magma beneath. In the extreme case the trapdoor action would permit the magma to escape to the surface, but there is no conclusive evidence that this happened in the case of the Gib. The presence of a small plug of trachyte breccia and trachyte on the western side of the fault (as shown on the map, text-fig. 1) indicates that there was a source of magmatic material on that side. It is suggested that this magma source was the remaining part of the initial laccolith shown on the left of the fault in stage 2 of text-fig 3.

In the third stage the resulting structure was denuded to expose the igneous rock as it is found today. At some stage during this process of denudation there was a period of extrusion of the later Tertiary basalts which now partly cover the extreme western portion of the structure. In the case of the Gib it was the eastern side of the initial dome which assumed the role of trapdoor action.

The intrusion, then, may be regarded as a kind of trapdoor-laccolith in which faulting has resulted from the failure by fracture of competent roof-rock with continued magmatic injection, and in which the eastern side of the initial structure has been differentially elevated by the pressure of incoming magma. In theory it would seem that special conditions are necessary for the formation of such a structure, the main one being that the intrusion should be initiated at or near the base of a moderately thick, competent, more or less horizontal formation at rather shallow depth. It is quite conceivable that a sill might behave similarly, with the direction of faulting perhaps controlled by pre-existing joint directions in the roof-rocks.

That such processes can, and do operate is visibly demonstrated in the active lava lakes of present-day volcanic regions, as is very clearly shown in some of the excellent vulcanological films seen in recent years. In some of these a close-up of the surface of the lava lake shows the rapidly congealed surface crust being arched up and fractured by the rising lava from beneath, and quite commonly one side of the fractured crust will rise like a trapdoor, allowing the lava to well out or issue forth as a fissure jet. There are, of course, very obvious differences between these two phenomena, but at the same time, they are of essentially similar kind and cause.

IV. Conclusion.

A short review of the literature of Mt. Gibraltar has been presented, and it has been shown that the intrusive igneous rock is a medium-grained ægirineaugite microsyenite characterized by the presence of ægirine, ægirineaugite and augite, between which pyroxenes there seems to be a continuous compositional gradation. The microsyenite is transected by numerous pegmatitic veins carrying sanidine, ægirine, arfvedsonite, riebeckite and quartz, though quartz is generally absent from the microsyenite itself.

It is proposed that the structure of the intrusion is that of an asymmetrical, contemporaneously faulted laccolith in which faulting has resulted from the failure by fracture of competent roof-rock with continued magmatic injection, and in which the eastern side of the initial structure has been differentially elevated by the pressure of incoming magma. There is no conclusive evidence of the magma having broken through to the surface.

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A STUDY OF LAYERED SEDIMENTARY MATERIALS IN THE RIVERINE PLAIN, NEW SOUTH WALES.

By C. A. HAWKINS,
and P. H. WALKER.

With four Text-figures.

INTRODUCTION.

The material discussed here is from hand-bored sections of sedimentary layers in two portions of the Riverine Plain of south eastern Australia (Butler 1950). A number of soil surveys have been carried out in this region, Taylor and Hooper (1938), Butler et al. (1942), Smith et al. (1943), Smith (1945), and Johnston (1953). These have been for the most part in the extreme south of New South Wales and the north of Victoria. Climate, vegetation and topography in relation to soils have been dealt with in these reports and need not be discussed here.

Dealing with the region in his theory of " Prior Streams ", Butler (1950) stated that the alluvium deposited by the prior streams " . . . appears to be continuous in the horizontal plane . . . " and that " . . . the prior stream formations . . . are the last of a series of alluvial systems deposited on the plains during late Pleistocene times ". More recently, with the accumulation of further information, Butler (priv. comm.) has suggested that these streams did not build overlapping layers on all parts of the plain and that large areas of older sediments occur at the surface in the wide interfluves. Investigations by several workers support this view.

The occurrence at the surface of different layers has made necessary a more detailed examination of their vertical assemblage and relationship in respect of age, origin and mode of deposition. Such an investigation has been attempted here by the study of two sections viz : the Cararbury section just south of the Murrumbidgee River, seven miles west of Darlington Point and the Warrawidgee section some fifteen miles to the north-west on the edge of the plain, twenty miles west of Griffith.

I. THE CARARBURY SECTION.

The Cararbury section comprises three landforms which are typical of the proposed " Billabidgee " area, lying between the Murrumbidgee River and Billabong Creek.

These are :

   (i) Treeless, or almost treeless plains occupying a large percentage of the area.
   (ii) Channel deposits (i.e. stream bed and levee) of the prior stream systems.
   (iii) Sand dunes, often associated with prior streams but occasionally isolated.

The section (1·5 miles in length) intersects each of these units.

Reference to the scale diagram, which for convenience has been marked off into three units A, B and C, will show the actual relationship of the various layers to one another in the field. The main features of each layer are described in the legend below each unit. The layers are given symbols since the authors feel there is no justification for attaching names to the various deposits at this stage. There are two main symbols—R and H—all deposits bearing the same letter having similar chemical and/or physical features but differ markedly from those bearing the other letter. The letter R has been used for light, micaceous, non-calcareous sediments showing lateral variations in texture and of undoubted riverine origin while H has been attached to uniform, fine textured, calcareous deposits showing no lateral texture grading. The subscripts indicate differences in age.

Before proceeding to a description of these layers it is necessary to establish, for both the Cararbury and Warrawidgee sections, the bases for distinguishing between the two categories of material (R and H for Cararbury, P and S for Warrawidgee) and between layers within each category. It is necessary also to distinguish the extent of weathering prior to deposition, from weathering, leaching and soil formation since deposition. The latter consideration is required in any attempt to assess the conditions and mode of deposition, the nature and duration of the subsequent climate and the age of the deposit.

Bases for distinguishing between layers—The difference between light riverine material (R) and heavy material (H) is obvious in the field. The former varies in texture from coarse sand and gravel to sandy clays, is often mottled with yellows ($2 \cdot 5$Y 6/4) and reds ($2 \cdot 5$YR 3/4), has abundant unweathered mica fragments, is loose or very friable and usually non-calcareous. The latter, on the other hand, is uniformly heavy or medium clay, dominantly grey in colour (5Y 7/2), but sometimes brown (5YR 4/4), has no visible unweathered mineral fragments other than quartz and is relatively dense except where granulation has developed viz. in gilgais on P_3. Moreover, the boundary between the two is sharp in most cases where one overlies the other.

Between the heavier flood plain material from the prior stream and the H layers, the distinction is not so clear because the texture and colour are the same and one layer grades laterally into the other. The criteria here are (a) for the riverine material, the presence of fine mica in the sand fraction*, progressive decrease in lime away for the stream bed to a trace or nil in subsoils of the far flood plain, general relationship to the prior stream soil sequence and (b) for other heavy materials (H), absence of mica, uniform texture and lime content over wide areas, lime at shallow depth (12–18 inches) and continuing thence throughout. It seems that at Cararbury very little heavy sediment was deposited by the prior streams. More would be expected at Warrawidgee since the stream there is almost dissipated (see Butler 1950). For example, at sites 36, 37 and 38 at Cararbury where the soil profile at the surface is heavy textured, the subsoil is light riverine material. It was at first thought that the surface was a thin deposit of H_3 but this was ruled out since there is mica in the upper part. A mixture of light riverine material with perhaps a preponderance of H_3 is indicated here.

The criteria for distinction between layers within one category will vary somewhat from place to place. Fortunately at Cararbury most of the heavy layers are separated from one another by riverine deposits. When two heavy layers occur together each can be indentified by first examining them where they are separated by a riverine deposit in an adjacent position, and thence tracing the boundaries to the interface. The characteristics of such interfaces are a change in colour, usually from brown to grey, gypsum accumulation and

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* Suggested by Dr. D. C. van Dijk and Mr. T. Talsma, C.S.I.R.O. Div. Soils, Griffith.

a sharp change in the form and/or distribution of lime. In addition, manganese oxide as a staining on the ped faces makes its appearance in the grey layers. Sometimes a marked change in consistence was used, as in the case of P_4/P_3 and P_2/P_1 at Warrawidgee. Apart from minor differences, H_1 and H_2 at Cararbury are almost identical and are only separated because a riverine layer occurs between.

Distinction between the light riverine layers was only possible in the case of R_2 and R_3 at Cararbury. Where both are exposed, the extent of weathering
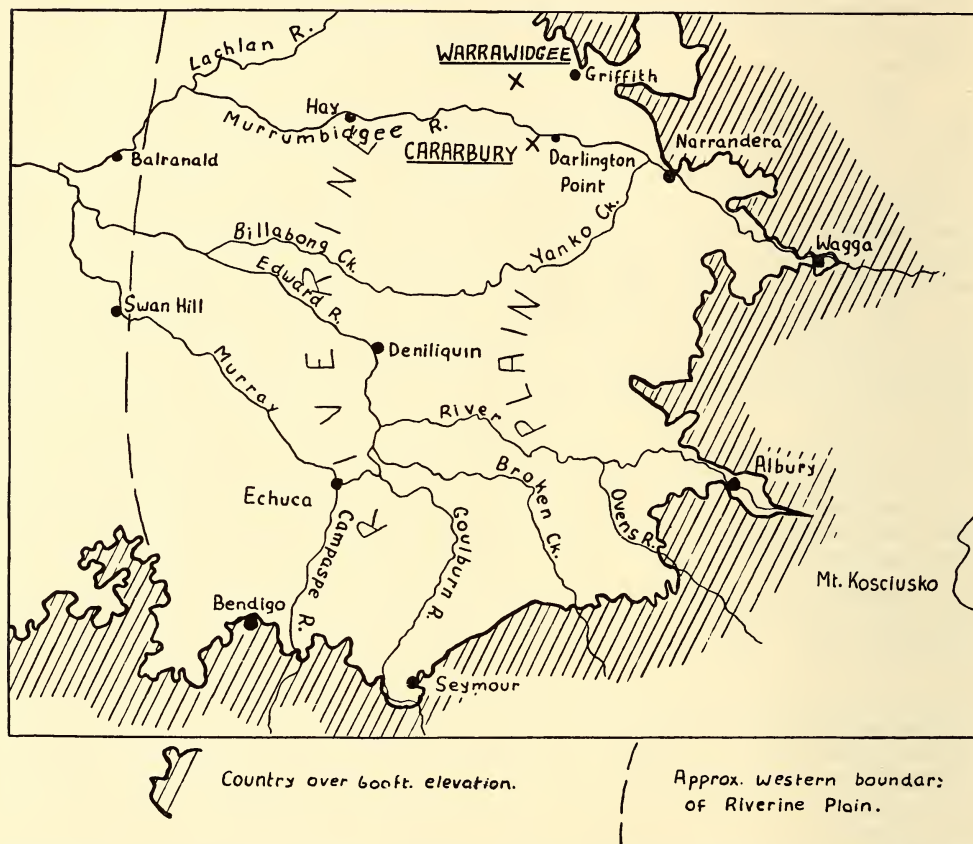
Text-fig. 1.—Map showing location of Cararbury and Warrawidgee sections in the Riverine Plain.

Scale : $1'' = 60$ miles.

and leaching is used, as will be seen later. Where R_3 overlies R_2 it is based on a change in colour, texture and lime content and form across an interface. The narrow trenches a, b, c at Cararbury are included in R_3 because of (a) the abrupt change from R (1–2) sediments to coarser R_3 over an almost vertical boundary and (b) the mild weathering and leaching of R_3 deposits.

Distinguishing between pre-depositional weathering and post-depositional soil formation—This is based on two assumptions ; (1) that any sedimentary deposit has undergone some weathering at the time of deposition and (2) that subsequent exposure will result in soil formation, the soil so formed depending on the parent material and nature and duration of climate.

Examination of the lighter riverine sediments at the surface shows that soil formation processes have affected the parent material only slightly below 42 inches (deeper in the case of sand deposits).   This material below the soil profile is taken as being broadly typical of unaltered parent material of its type.   In the case of the heavy layers, weathering prior to deposition appears to have been considerable and characterization of unaltered parent material is more difficult.   Where a deposit has a fine-earth lime throughout it is assumed that very little leaching has taken place and such material can be taken as being virtually unaltered.   Where lime occurs as visible concretions, mild leaching is indicated during or subsequent to deposition, but absence of lime need not indicate greater leaching unless accompanied by other evidence of soil formation.

The authors realize the difficulty in distinguishing between depositional and subsequent pedological changes down a profile (e.g. texture changes).   Only where it can be shown that other profile features, formerly present, have been destroyed or removed can such changes be attributed to soil forming processes. It must be borne in mind that some profile features such as organic matter in the A horizon or a thin A horizon (1 inch thick), as is found on many soils at the surface today, can easily be removed by erosion.   Their absence does not rule out the possibility of the former existence of a soil but it is necessary to examine considerable areas of the layer surface, here and elsewhere, to prove this.   In the absence of carbon for dating purposes and fossils, the study of such buried soil profiles gives the most reliable estimate of age of the deposits, duration of exposure and climatic conditions prevailing during exposure.

Description of the Layers—With one or two exceptions all the H layers are grey or yellowish grey, medium to heavy clays and are very uniform in texture both laterally and vertically.   They are almost always calcareous having slight to light amounts of lime in the form of comparatively large (up to 1 inch) flinty, mixed lime-manganese oxide concretions.*   The presence of much manganese oxide as a black staining on the faces of the peds is another constant feature (except for H_3) not found in the lighter riverine sediments. Gypsum is present at the interface where two heavy layers meet but is absent where the adjacent layer is a light riverine deposit.

A puzzling feature is the absence of any buried profiles on the upper surface of these layers.   A more detailed consideration of the heavy layers is necessary at this point.

Layer H_1—The lime is evenly distributed vertically except in one case where there is a build up within 36 inches under an overburden of R_1 sand. Gypsum is absent presumably because of the light textured covering deposit. No texture profile was found but weathering and leaching were sufficient to mobilize calcium, magnesium and manganese and deposit them in the form of mixed concretions.   The absence of a texture profile may be explained as the result of subsequent erosion during the riverine phase which laid down R_1 material, or soil development on heavy, base-rich parent material under arid to semi-arid conditions.

H_1 as such occurs only in the southern unit but it is thought that H_1? in unit A which is an acid, grey light clay could be a remnant of the H_1 surface which in unit C was stripped and replaced by R_1 riverine material.   This would require considerable weathering and leaching suggesting long exposure before truncation.

Layer H_2—This layer is very similar in appearance to H_1, from which it is separated by R_1, but differs from H_1 chemically in several respects.   Lime decreases with depth and reaction becomes slightly acid (pH 6·5) ; there are

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* Analyses of similar concretions from Warrawidgee soils show 21·7% calcium, 1·3% magnesium and 1·7% manganese.

slight to light amounts of gypsum at the H_2/H_3 interface and penetrating some 30 inches into H_2. Under the dune in Unit A, H_2 has no gypsum, is lower in lime—trace to slight amounts—and is generally more acid than in Unit C.

Apart from the occurrence of gypsum in parts of H_2, the extent of leaching and weathering appears to be much the same as for H_1. Since it is clear that a period of riverine activity intervened between H_2 and H_3 the apparent mild weathering (see lime content and alkalinity) is difficult to explain. It is possible that the climate was too arid for more than a very narrow zone of soil weathering and that this weathered layer has been removed.

Layer H_3—Although very similar to H_1 and H_2 in many features, several important differences are observable.   It is only 3–4 ft. thick, brown to yellowish brown instead of grey and has only slight amounts of lime in the form of finer, soft concretions with no black manganese oxide staining.   Further it has a strongly differentiated soil profile (Willbriggie series)* at its surface.   This soil has two to four inches of brown to light brown clay loam A horizon, often platy structured and showing no clearly defined bleached zone—rather the whole A horizon is brittle and pulverulent.   The B horizon is weakly structured, dark brown or reddish brown heavy clay, dense and hard when dry and plastic when wet.   Lime occurs at about 12 inches and the profile becomes lighter coloured and more friable with depth, but the texture remains heavy. A brown puff soil, Yooroobla clay (Churchward and Flint, 1956) may occupy from 10–40% of the surface area.

The H_3 layer runs north from the fringe of the southern dune and is itself partly covered by a thin layer of more recently blown sand.   In this position a solodized solonetzic soil with a pseudo-A horizon, Danberry sand (Churchward priv. comm.), has developed.   It has a marked bleached A_2 horizon overlying a cemented, strongly domed, sandy clay B horizon ; a trace of lime often occurs at about 24 inches.   The presence of solodized solonetz soils in similar positions in the Pilliga scrub N.S.W. was noted by Waring (1949).   It seems that the presence of an artificially formed B horizon from the outset of soil formation causes more rapid solonization in such positions, compared with adjacent positions on heavy sediments.

Where the H_3 layer is mixed with R_2 riverine in Unit B, a heavy, slightly micaceous, sharply differentiated profile develops with a 6 to 8 inch, partly bleached A horizon of clay loam texture.   North of the northern dune, H_3 is mixed with sand from the dune to give a sandy surface overlying a mixed sandy medium clay B horizon which becomes heavy clay with depth.   Here the H_3 layer does not overlie part of an old dune as is the case in the south.   At both dunes the H_3 layer runs up to but does not encroach beyond the base of the dune.

This layer is widespread as the surface layer over considerable areas in the north of the region and is usually treeless except for isolated boree (myall) trees (*Acacia pendula*).   It is felt that the H_3 is the Widgelli parna, a material of æolian origin (Butler, 1956)*.   It is not found on the dune slopes and crest, for sand movement would prevent such fine particles from settling.   The H_3 post-dates the older dune to the south but antedates the crest material of both dunes.

The "R" Layers—These layers have a number of features in common but differ markedly from the H layers.   They are generally light textured and often show the lateral grading away from the stream bed characteristic of riverine deposits.   They are all micaceous and have much less lime than the heavy layers.

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* Hawkins and Beattie, A soil survey of Warrawidgee Estate, Griffith, N.S.W. (To be published).
 * Butler, B. E., 1956.   Parna, an Æolian clay. *Aust. J. Sci.*, **18**, 145.

UNIT C

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                                                                        56
                                                                        ⊥
                                                              Young Dune
                                                        R₃         55
                                    53         54
45         46  48 50  51  52                         R₂    Older Dune
                47 49                                  _____Horizontal Datum
                              R₂
                            •  •  •                                   R̄₂
                                  •         H₂
            •               •
                                        R₁
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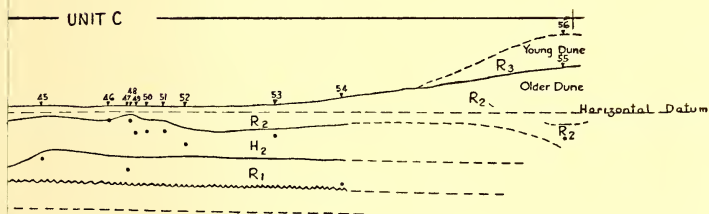
micaceous, acid, loose sand.
eavy clay ; calcareous with gypsum at depth.
sand with solodic soil profile.
bright, micaceous, coarse sand and gravel ; sometimes fine textured.
alcareous, gypsum at H2/H3 interface ; manganiferous.
brown sands and sandy clays ; little or no lime.
ealcareous ; non gypseous, alkaline ; manganiferous.

CARARBURY SECTION
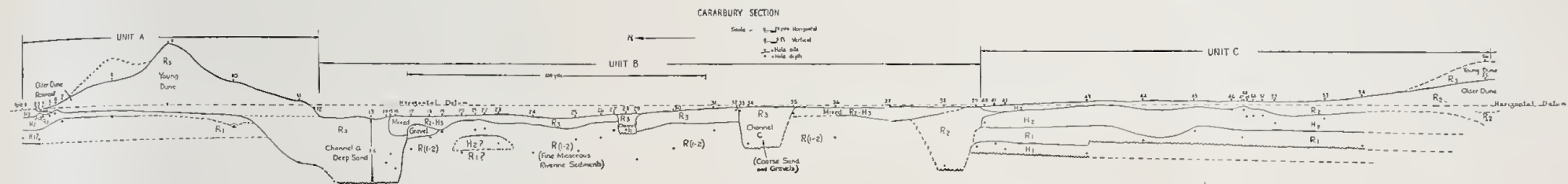
Unit A.

R3. { Young Dune
     and
     Portion of channel a : Brown and yellow brown micaceous, acid sand.
H3. Uniformly heavy, yellowish brown clay ; slightly calcareous.
R2. { Remnant of old dune : Red, brown and yellow, acid, micaceous sand and sandy clay.
     Lense of riverine material : Yellow brown, micaceous, fine sandy clay or clay loam ; alkaline ; no carbonate.
H2. Uniformly, yellowish grey, medium clay ; slightly calcareous and manganiferous.
R1. Yellowish brown, micaceous, sandy clay.
H1. Uniformly, grey, light clay ; acid ; non calcareous ; manganiferous.

Unit B.

R3. { Channel a : Yellow brown and brown, micaceous acid sand as in young dune.
     Channel b : Yellowish brown, fine sandy loam to loam ; slightly calcareous ; soil profile of sand surface and sandy loam B.
     Channel c : Brown coarse sand and gravel with gradual texture profile.
H3. Brown, heavy clay ; no lateral grading : micaceous where mixed with R2 ; heavy texture soil profile.
R2. Sandy clay loams, loams and light clays ; micaceous and occasionally calcareous ; some mixing with H3.
R1-2. Main channel fill ; fine sandy clays and clay loams ; highly micaceous ; non calcareous.
H2. Uniformly grey medium clay ; slightly calcareous.
R1 ? Micaceous sandy clay material.

Unit C.

R3. Young dune ; reddish brown. micaceous, acid, loose sand.
H3. Reddish or yellowish brown, heavy clay ; calcareous with gypsum at depth.
R2. Older dune : Grey and brown sand with solodic soil profile.
     Buried stream deposit : Clean, bright, micaceous, coarse sand and gravel ; sometimes fine textured.
H2. Uniformly heavy grey clay ; calcareous, gypsum at H2/H3 interface ; manganiferous.
R1. Micaceous, yellowish grey and brown sands and sandy clays ; little or no lime.
H1. Uniformly heavy, grey clay ; calcareous ; non gypseous, alkaline ; manganiferous.

In fact they are mostly acid in reaction. Colours are not uniform but vary from reds to browns, yellows and greys. The R layers also differ from H layers in being non-gypseous and having little or no manganese oxide on the soil ped faces and none in the lime concretions*.   Individual R. layers are as follows.

Layer R_1—This layer is 3–5 feet thick and like the surface riverine layers is composed of micaceous sand, gravels and sandy clays showing both lateral and vertical texture variations. In most cases the texture lightens with depth, in two places passing into sand, and the visible mica content increases downwards. Lime is variable and where present is associated with heavier sediments.

The increase in mica with depth and the development of concretionary lime are taken as indications of mild weathering of the layer before deposition of H_2. Because of the heaviness of the H_2 layer, it is likely that there has been little erosion of the original R_1 surface, since uniformly fine sedimentation would take place only under relatively quiet conditions. If this is so then the evidence would suggest but a short exposure of R_1, certainly less than the exposure of H_1, prior to H_2 deposition. Layer R_1 is generally restricted to Unit C ; a small pocket is also evident under the southern edge of the dune in Unit A.

Layer R_2—Only materials which can be definitely be placed as being between H_2 and H_3 on the time scale are included.   The bulk of lower riverine material in Unit B may belong to R_1 or both R_1 and R_2 and will be discussed as R (1–2). There are however two deposits which can be included in R_2 with reasonable certainty.

1. The buried water-worn, micaceous, coarse sand and gravel under the southern dune and the overlying dune itself. The crest of this dune is younger and thought to be R_3 material.

2. The small deposits of micaceous loams and light clays with gravel between sites 38 and 41 in the middle of the section.   In addition there are two deposits of mixed R_2–H_3 material in Unit B.

The degree of weathering of these deposits varies. The small riverine deposit under the southern dune is fresh and unweathered and was therefore exposed only briefly, if at all. This indicates that the covering dune was deposited on top soon after the former was laid down.

The R_2 dune on the other hand shows evidence of much stronger weathering. Under the capping of more recently blown sand (referred to above as R_3) there is a profile (55) with a band of lime accumulation 18 inches thick.   A still more highly weathered profile occupies the exposed edges of the dune outside the cover of the more recent capping.   Profile 54 on the flank of the old dune is an acid solodic soil with a deep, bleached A horizon 25 inches thick, overlying a narrow, sandy clay B with very weak doming.   The B horizon is mottled and penetrated by tongues of silica flour from the A_2 which, together with acid reaction and absence of mica, suggests intense weathering.   The old dune surface has been exposed longer than other layers and this is reflected in profile morphology.

On the mixed R_2–H_3 material the profile is well differentiated and resembles that developed on the H_3 layer.   This supports the authors' views on the origin and age of this material.   The riverine cycle which deposited R_2 is thought to have involved first an actively cutting phase, followed by a depositional phase in which the stream flow became progressively weaker.   Somewhere in the latter part of this cycle the southern dune was blown up followed by the deposition of H_3.   During this deposition the stream flow, though weak and

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* Analysis of such concretions from Warrawidgee shows $26 \cdot 6\%$ calcium and $1 \cdot 6\%$ magnesium with no manganese.

intermittent, was sufficient to mix late R_2 and H_3 materials.   Finally, R_2 stream flow ceased altogether.

Layer R (1–2)—This constitutes the lower mass of the fine, highly micaceous sediments of the wide river trough in Unit B.   The trough containing these sediments is $0 \cdot 7$ miles across.   It is a product of powerful stream activity which has truncated the pre-existing landscape and then filled the trough with a complex of predominantly fine micaceous material.   Other riverine materials e.g. gravels and sands occur intermittently and represent short depositional breaks.   The R (1–2) material is distinct from R_3, the latter being confined to three deep channels cut into the R (1–2) complex.

Because of the complexity and non-continuity of layers it is not possible to determine to which period of deposition (that giving rise to R_1 or to R_2) the bulk of the material belongs.   It is possibly the product of both periods, each characterized by cutting followed by deposition.   The stump of heavy material in Unit B is thought to be H_2 and underlain by what is therefore presumed to by R_1 material.   If this be the case the bulk of fill material in the trough is R_2. However identification of the heavy material as an H_2 remnant is uncertain. It therefore seems safer to call the material R (1–2).   On the other hand there is evidence which suggests that the upper part of this layer is R_2 mixed with H_3 because at sites south of 23 in Unit B there is a depositional break at 4 to 5 feet.   Below and above this boundary, lime accumulation maxima occur associated with a sharp colour and texture change across the interface.   The lime below the interface is partly in the form of fine-earth and does not show the lateral gradations associated with lime in riverine sediments, whereas the lime above, belonging to R_3 sediments, is in the form of concretions.   The finely-divided lime is thought to be a " young " form, not mobilized, indicating restricted weathering.   Its form and distribution in the lower layer is due to contamination by H_3.

Mixed R_2/H_3 material comes to the surface on either side of the river trough so that at the close of H_3 deposition there existed a shallow depression across the stream trough which provided a course for later stream-flow—that giving rise to R_3.   During this latest phase the trough was filled to its present level.

Layer R_3—This layer is confined to the three narrow channels a, b and c in the diagram and shallow flanking deposits covering a very restricted area.

The profiles formed on the coarser stream bed sediments show evidence of youthfulness in that they are micaceous throughout and have no sharp horizon differentiation.   In channels a and c the parent material was acid but in b slight fine-earth lime was found.   This latter trench is of interest since it contained bones of two native rodents* and some small snail shells at a depth of 5 to 8 feet.

After a careful examination of the pit from which the remains were taken, the authors concluded that because of the undisturbed nature of the profile and the wide vertical distribution of the bones and shells, the surrounding soil was not burrow fill but that the remains had been buried in the ordinary coarse of deposition.

It is significant that the animal remains were relatively fresh in appearance and not fossilized by lime or silica replacement and that the soil profile above showed slight but distinct differentiation of lime and texture.   This suggests that channel development and in particular channel fill, must have taken place in late geological time.

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* One was a species of *Pseudomys*—a mouse-like rodent of the inland, and the other the White-tailed Rabbit Rat (*Leporillus apicalis*), once plentiful on the plains but exterminated as a result of settlement and introduction of the fox.   Both are present day species but it is not known when they first appeared.

These narrow stream trenches are merely steep sided channels gouged out of the plain. The streams have deposited very little material laterally, except in the case of channel b. They are evidence therefore of a sudden onset of erosion followed by an equally rapid onset of aridity causing the streams to dry up. With the coming of arid conditions dunes were built adjacent to the source of sand—the stream beds. It is thought that the bulk of the sand for the northern dune and a thick capping on the southern dune came from this source. In each case an old dune remnant formed the core about which the fresh material accumulated. Evidence for this is the difference between the profile on the crest and that at the base in the northern side of each dune.

These dunes are at present vegetated by *Callitris glauca*, *Stipa* sp. and *Aristida* sp., indicating a relaxation of the aridity which led to dune formation (see Butler, 1950).

II. WARRAWIDGEE SECTION.

The Warrawidgee section lies to the north of Cararbury and the Murrumbidgee River, on the edge of the plain where the riverine pattern and hill slope country overlap. The area is characterized by low residual hills around the bases of which are distributaries of the prior streams which lose their identity in this section of the plain.

It is apparent from the prior stream courses that they receive little or no run off from the residual hills, but, like the present Murrumbidgee River which is a stream of transit on the plains, they had their watersheds on the western slopes. Unlike the Murrumbidgee however, these streams become lost on the plain. The Warrawidgee sections begins on one of these small distributaries and runs at right angles to the stream course off the riverine material to the base of one of the low hills.

In this part of the region the landscape has four units.

  (i) Low hills—beyond stream influence.
 (ii) Plains, sparsely timbered and covered by sediments not deposited by the uppermost prior streams.
(iii) Prior stream deposits.
(iv) Sandhills associated with the prior streams.

The Warrawidgee section crosses only the plain and prior stream units.

Details of the Warrawidgee Section.

Reference to the scale drawing of the Warrawidgee section and accompanying legend will show the relationship of layers to one another. As in the Cararbury section symbols have been used to designate the layers—in this case P for the heavy, uniform, calcareous layers and S for the light, variable, stream deposits.

Descriptions of Layers—Although in their main features the heavy and light layers here closely resemble their counterparts at Cararbury, certain differences are apparent in the field, in particular the presence of high amounts of fine-earth lime in the heavy layers of Warrawidgee. Further, the layers of each group differ among themselves and a brief description of these differences is desirable.

Layer P_1—This forms a basal layer for the whole section. It is a dominantly grey, uniformly heavy clay of tough consistence, slightly acid for the most part but occasionally having a trace of carbonate in the upper part. Manganese oxide streaks and veins are abundant on the faces of the peds. The almost complete absence of lime and the acid reaction set this layer apart from the otherwise similar calcareous layers.

WARRAWIDGEE SECTION
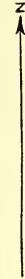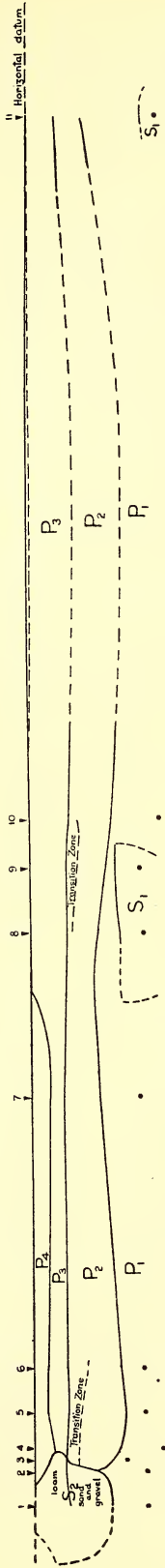
Text-fig. 2.

S_2 An upper layer of alkaline loam and a lower layer of acid, coarse sand and gravel; micaceous.

P_4 Featureless, massive, brown, heavy clay; trace lime; non-micaceous.

P_3 Yellowish brown to reddish brown heavy clay; calcareous; moderate fine earth lime; alkaline; non-micaceous; manganiferous; puffy where surface layer.

P_2 Grey, heavy clay; calcareous and gypseous; heavy fine earth lime; non-micaceous; manganiferous.

P_1 Grey, heavy clay; non-gypseous; occasionally trace lime; neutral to acid; dense and highly plastic; manganiferous.

S_1 Micaceous, fine sandy clay; trace lime.

Layer P_2—This lies immediately above P_1 into which it grades fairly rapidly. It is more highly calcareous than similar H layers at Cararbury and has lime in two forms, viz. the large flinty mixed lime-manganese oxide concretions so common at Cararbury and fine-earth lime indicated by the vigorous effervescence of the fine earth to dilute acid. Slight to light amounts of crystalline gypsum occur at the P_2/P_3 interface.

Layer P_3—This layer outcrops between sites 7 and 11 but between sites 7 and 4 is covered by P_4. By contrast with the heavy layers beneath, it is yellowish to reddish brown in colour as was layer H_3 at Cararbury which it resembles closely. It is less calcareous than P_2 below but more calcareous than its counterpart H_3 in the southern section. A well-developed soil Willbriggie clay loam, forms the background type at the surface with Yooroobla clay on the puffs. This latter type occupies from 60–80% of the surface area. These puffs are very friable with calcareous fine earth even at the surface.

Layer P_4—This layer occupies the surface between sites 2 and 7. It is a dark brown heavy clay with a thin " skin " of strongly granulated soil at the surface, beneath which it quickly becomes massive. The surface is incipiently puffy, quite treeless and supports only a sparse cover of annuals with very little grass. The soil developed has been named Bringagee clay.* Only a trace of carbonate was found, the whole layer being a uniform, featureless brown clay in section down to about $2\frac{1}{2}$ feet where P_3 comes in.

The Lighter " S " Layers—These generally resemble the " R " layers further south with some individual differences worthy of comment. The stream deposits are confined to a small lens under P_1 denoted as S_1, and the narrow trench on the left side of the section—S_2. Layer S_1 is a yellow grey and reddish brown, slightly acid, micaceous, fine sandy clay with a trace of concretionary lime quite free of manganese (see supplementary note). Layer S_2 is coarser in the lower part and has two zones—a lower bed of coarse sand and gravel and an upper bed of loam to sandy clay loam. Both are acid but there is a zone of lime accumulation in the soil developed on the upper portion (Marah series).† This soil has two inches (surface has been scalded) of bleached clay loam surface overlying a sandy medium clay B horizon which is very dense and hard with a trace of lime at 14 inches. Slight amounts of concretionary iron oxide occurs in the A_2 horizon.

The heavy layer P_4 partly covers the S_2 sediments and wedges out away from the stream bed over the adjacent heavy layers. The sedimentary sequence indicates a progressive weakening of stream activity until finally heavy sediments were deposited in the stream bed itself. Evidence suggests that S_2 post-dated and cut through the P_3 layer but some mixing of heavy stream sediments and P_3 material took place to give a strip of P_4 adjacent to the stream. The P_3 material adjacent to the stream was mixed with fine flood plain sediments and leached of its lime by stream flooding giving rise to the featureless, massive P_4 layer with its brown, structureless (except for a thin surface cover) Bringagee soil. By contrast the soil on adjacent, unmixed P_3 material is a brown, calcareous, friable type with two inches of clay loam surface.

DISCUSSION.

The main feature revealed by the Cararbury Section is the alternate deposition of heavy, uniform, calcareous material and lighter, variable, riverine material. This sedimentary array is the result of repetitions of such a cycle. Variations do of course occur between cycles but their basic features are the same.

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* See " A Soil Survey of Warrawidgee Estate, Griffith, N.S.W. "
† Johnston, E. J., 1953.

At Warrawidgee on the other hand, most of the riverine layers are missing leaving only a succession of heavy layers. This is not unexpected as the Warrawidgee area is on the edge of the zone affected by prior streams and furthermore, at any particular place it is unlikely that all layers would be present since none is continuous.

In the absence of riverine layers correlation with Cararbury is possible if it is assumed that all the heavy layers are present on Warrawidgee. The surface layer P_3 with its Willbriggie soil is a good counterpart of the H_3-Willbriggie layer at Cararbury. Although P_3 material is more calcareous, the degree of profile differentiation, the colour, texture and consistence of both are so similar as to suggest a similar origin and time of exposure to soil forming processes. On this basis the two sections can be correlated as in Table I.

The area studied is a depositional zone receiving its material from outside, so that while local changes express themselves in re-sorting within the region the underlying causes for the depositional rhythm must be sought elsewhere— on the watersheds to the east and also in places further west. Climatic changes in these bordering zones appear to provide a satisfactory explanation of the changes in deposition on the plain. Tectonic changes in the watersheds would hardly have occurred with the steady rhythm suggested by the vertical assemblage found.

If Butler's theory of the origin of Widgelli material is correct (Butler, 1956) namely that it is an æolian clay called "Parna", and assuming a similar origin for other heavy, calcareous layers, then the depositional rhythm shown by the section is ultimately the result of a climatic rhythm of alternating arid and pluvial periods. Even if a fluviatile origin is proposed for these heavy layers it is still necessary to postulate climatic rhythm since the presence of dunes is independent evidence of aridity. Heavy fluviatile layers would then fit into a different position in the arid-pluvial cycle.

The principles underlying climate-stream relationship are not clearly established. Albritton and Bryan (1943) in their studies of the Trans-Pecos, Texas suggest that the "... alternating stages of erosion and deposition in valley flats . . . seem to have reflected alternations in climate from relatively moist to relatively dry, alluviation having occurred during the moist times and dissection during the dry."

On the other hand it can be concluded from the investigations of King (1953) that arid and semi-arid climates provide optimal conditions for erosion at stream headwaters. As the essential factor determining the erosional stability of a landscape is the vegetative cover it seems logical to suggest that if the natural vegetation was disturbed, for example during a climatic change from humid to arid, accelerated erosion would result with increased deposition in river valleys, because the water : sediment ratio would be greatly reduced.

A humid climate might be expected to provide optimal conditions for vegetative growth and despite the increased precipitation, erosion at the headwaters and deposition in the valleys would be at a minimum. Thus humid climates would seem to favour greater stream volume and less sediment while arid climates favour reduced stream volume and increased sedimentary load.

If these principles can be applied on a large scale to west flowing rivers in New South Wales, it can be argued that arid conditions causing landscape instability on the western slopes favour erosion there and the development of corresponding depositional terraces on the plains. Moist conditions would favour stability in western slope headwaters and the increased volume of water would cause cutting on the plains.

Although the conclusions drawn by Albritton and Bryan (1943) are at variance with the above, it is interesting to note that they suggest climatic changes as the cause of new erosion and depositional cycles.

TABLE 1.

Cararbury		Warrawidgee		Remarks.
Layer.	Description.	Layer.	Description.	
R_3	Coarse channel sediments.	S_2 and P_4	Coarse and fine sediments.	Uppermost riverine, soil development generally weak, strongest on S_2, where some ironstone accumulation occurs.
H_3	Uniform, heavy, brown, calcareous; Willbriggie soil.	P_3	Uniformly heavy brown, more strongly calcareous; Willbriggie soil.	Soil development similar; P_3 more calcareous; appear to be of same age and origin.
R_2	Micaceous riverine.	Absent.	—	Because of position on the edge of the plain this layer missing at Warrawidgee.
H_2	Uniform, heavy, grey, calcareous and manganiferous deposit; mild leaching (gypsum).	P_2	Uniform heavy clay, dominantly brown, more highly calcareous and manganiferous gypseous; weathering slight.	From position in sequence P_2 is same age as H_2 but much more calcareous. Both showing slight weathering.
R_1	Micaceous riverine.	Absent.	—	Stream carrying R_1 material did not reach the Warrawidgee section.
H_1 H_1?	Uniform, heavy, grey clay; calcareous, manganiferous. Uniform, grey, clay; non-calcareous.	P_1	Uniformly grey, heavy clay; manganiferous; non-calcareous; tough consistence.	Correlation uncertain: H_1 leached to considerable depth; surface erosion severe in Cararbury section to expose calcareous subsoil.
—	Not reached.	S_1	Micaceous riverine; slightly calcareous; restricted to narrow channels.	Represents a period when streams penetrated as far north as in S_2 times; surrounded by P_1 suggesting two phases in P_1 deposition.

TABLE 2.

Correlation of Layers with Climate.

Soil or Layer.	Properties.	Proposed Origin.	General Associated Climatic Regime and Changes Therein.	Tentative Pleistocene Correlation.
H₁	Grey, calcareous, heavy, moderately weathered, possibly truncated.	Æolian.	Comparative aridity at source to the west; stream activity very weak.	Riss-Wurm Interglacial to Recent.
R₁	Light, mixed micaceous sediments; moderately weathered.	Riverine.	Climate gradually becomes more pluvial; æolian sedimentation closes; streams at first actively cutting, later aggrading with onset of next arid period.	
H₂	Grey, calcareous, heavy, moderately weathered.	Æolian.	Comparative aridity, stream activity very weak, later strengthening.	
R₂	Mixed light micaceous sediments, slightly calcareous at top; represents close of R(1-2) described in text.	Riverine with later admixture of calcareous H₃.	At first more pluvial with powerful streams indicating prolonged wet conditions, followed by gradual onset of aridity. Conditions favourable for stream aggradation and dune building.	25,000–8,000 years ago.
R₂ dune	Brown micaceous sand.	Wind blown, riverine material.		
H₃	Brown, heavy, slightly calcareous with well developed profile at the surface (Willbriggie series).	Æolian (*Widgelli parna*).	Comparative aridity at source; stream activity very weak, later becoming stronger.	
R₃	Micaceous sands and gravels in narrow trenches; little or no flood plain sediments.	Riverine.	Rapid change to pluvial period of short duration, aridity follows quickly, conditions then favourable for dune building as stream flow ceases.	
R₃ dune	Yellow brown micaceous sand.	Wind-blown riverine material.	Aridity.	
Present Soils	Soils on tops of dunes, R₃ riverine and H₃ heavy layer.	Product of climate since close of last pluvial.	Relaxation of aridity; dunes vegetated; development of present climate; renewal of stream activity resulting in present rivers.	Late Recent 4,000 years ago to present day. (? B.C. to 1200 A.D.)

From a consideration of the work dealing with Pleistocene climatic changes outside the periglacial zone in the northern hemisphere (Zeuner, 1945, 1952) it appears that mild pluvial conditions prevailed during glacial phases alternating with warm dry conditions during interglacials and interstadials. On the evidence available similar alternating climatic conditions occurred in the southern hemisphere in areas remote from large ice sheets. In Australia the effects of the mainland ice sheets associated with the Kosciusko area are not known but the periglacial zone would have been very limited. The major fluctuations throughout therefore are alternating mild-wet and warm-dry climates which would govern the flow and sedimentary load of the west flowing streams and would also influence the soil forming climate in the deposition zone on the plains. These climatic changes would be reflected both in the nature of sediments and in the soil development on material already deposited.

Browne (1945) has drawn up a tentative post-tertiary chronology for Australia and in this it is suggested that this continent was not only influenced by ice sheets but also by the accompanying widespread Pleistocene climatic fluctuations.

If the layers described here have been deposited as a result of relatively arid periods throughout the upper stream course, useful time correlations are possible. The slightly differentiated soils on R_3 material are somewhat similar to soils of the Calamity sediments described by Albritton and Bryan (1943) as ? B.C. to 1,200 A.D. in age and the strongly differentiated soils on R_2 material may have a counterpart in soils of the Neville sediments, 8,000–25,000 years old.

In Table II the layers have been correlated with probable climatic and depositional changes, and ages are given tentatively where appropriate.

An examination of the bore log data for the area between Narrandera and Hay shows that the pattern of alternating heavy uniform calcareous layers and lighter, variable riverine material continues to great depth (200–1000 feet). The thickness of individual layers appears to increase with distance below the surface suggesting (a) that later erosion and depositional phases were of considerably shorter duration than earlier phases, and (b) that the deposits discussed in this study occupy only a small fraction of the total thickness of sediments and therefore represent only a relatively short period of geological time, probably the late Pleistocene. It appears then, that the ages given in Table II are of the right order of magnitude even if not specifically accurate.

Summary.

A study was made of near-surface layers at two sites, Cararbury and Warrawidgee, in the Riverine Plain, New South Wales. The distribution of the layers in this study is discussed in relation to the prior stream pattern of the plains described by Butler (1950). In both areas, uniformly heavy grey, calcareous clays of æolian origin (H and P layers), alternating with coarser variable riverine material (R and S layers) were found.

Some of the riverine layers found at Cararbury appear to be missing in the Warrawidgee section and this is attributed to the position of the latter on the fringe of the zone of prior stream influence.

The alternate deposition of æolian clay and riverine sediment is considered to be the result of arid and pluvial climatic phases during late Pleistocene and Recent time, the riverine layers being deposited toward the close of each pluvial phase and the æolian clays, together with sand dunes, being features of the arid phases.

Some degree of weathering was evident in all materials and although no complete, buried, soil profiles were found, it is suggested that soil forming

processes had brought about differentiation of lime, gypsum and manganese constituents in certain layers.   Both the nature of the depositional layers and the degree of weathering showed reasonable correlation with materials described by Bryan and Albritton (1943) in the Trans-Pecos Texas.   Very tentative datings have been given to the major phases represented in the Cararbury and Warrawidgee areas, covering a period from the Riss/Wurm Interglacial to Recent.

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SUPPLEMENTARY NOTE.

During the field work on the Warrawidgee section two profiles (10 and 11) were samples to depth to find if the lime and soluble salt profiles supported the field observations regarding the existence of two calcareous layers overlying a highly leached layer.   Total soluble salts, chlorides and carbonate estimations* were carried out on these samples.   In addition a number of samples of concretionary lime were collected from each layer to test for the presence of manganese.   All these samples were analysed for carbonate and some for calcium, magnesium and manganese.†   The results of these analyses are set out in the table and the figure below.

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* Total soluble salts were estimated on a 1 : 5 suspension ; chlorides were estimated by titration with silver nitrate using a Mullard potentiometric titration unit ; carbonate determinations were done by the Novarro-Sagrista method (Cemerto-Hermigie, 1953, **19**, 86).

† Carbonates were estimated by Novarro-Sagrista method, calcium, magnesium and manganese on a Hilger medium quartz spectrograph after soln. in 5N HCl and calcium by the versenate method.

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The carbonate profiles shown in Fig. 3. confirm the observation that layer P_2 is more calcareous than P_3 and that layer P_1 is almost free from carbonate. The carbonate maximum in layer P_3 for profile 10 is not repeated in profile 11
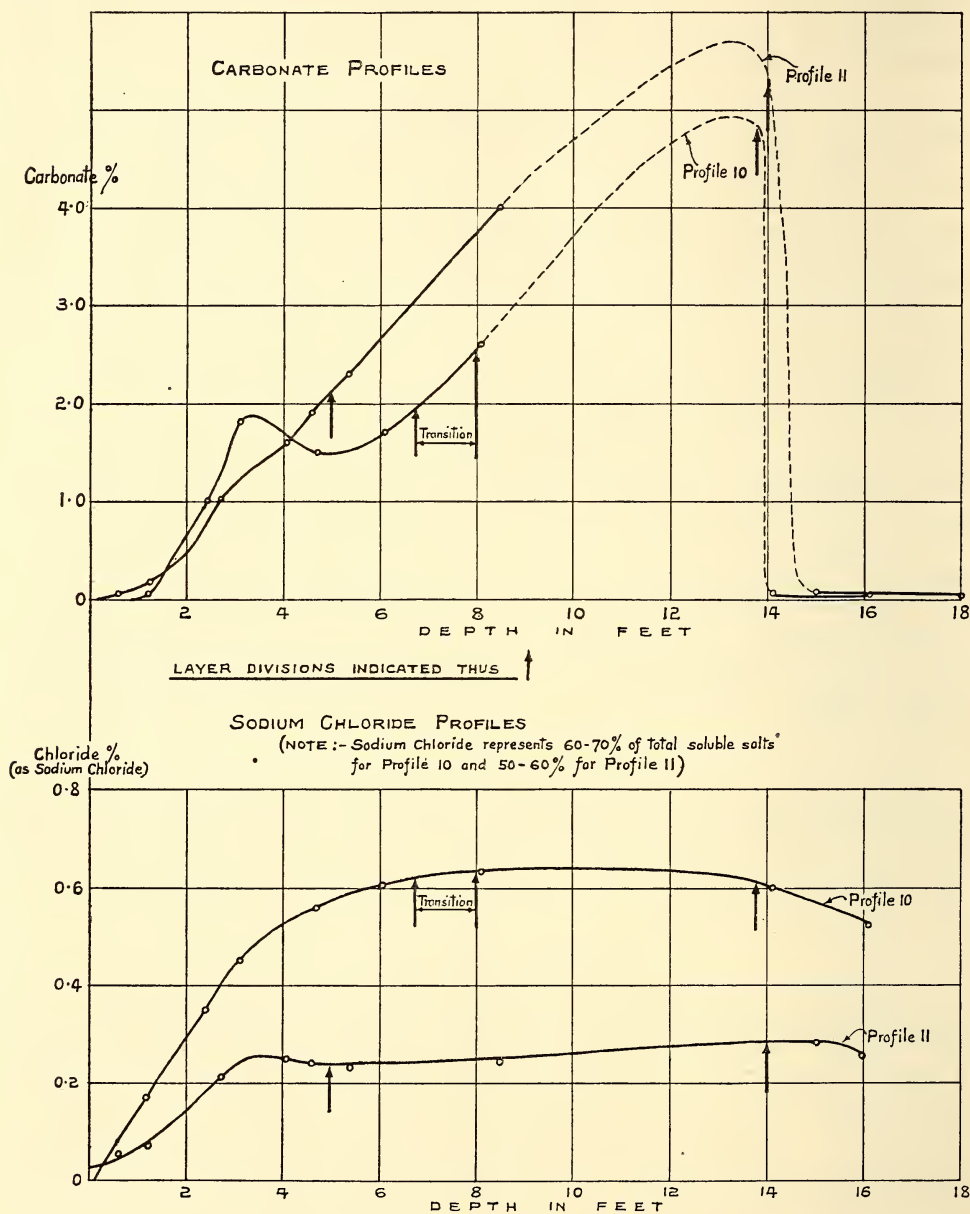
Text-fig. 3.

although there is a change in gradient.   Profile 10 is in a local, slight depression and its surface colours suggest wetter conditions than for profile 11.   This may account for the more definite maximum in profile 10.   Both profiles show only mild leaching although the A and B horizons are strongly differentiated.

The chloride profiles show a rather constant level of salt for P_2 with a steady rise through P_3 to this level. The salt content falls off only slightly into P_1 indicating that some leaching of salt has taken place across the P_2/P_1 boundary although very little carbonate has been moved across this interface.

The concretion analyses shows a low but appreciable manganese content for the black stained concretions from the heavy layers. By contrast a typical sample of concretions from light riverine material shows no manganese.

TABLE 3.

Type of Concretions.	Layer.	% Carbonate.	% Ca as CaCO$_3$.	% Mg as MgCO$_3$.	% Mn as MnO$_2$.	% Insol. Matter (Approx.)
¼″–⅛″ diam., slight black staining ..	P_3	69	—	—	—	
¼″–⅛″ diam., slight black staining ..	,,	58	—	—	—	
¼″–⅛″ diam., slight black staining ..	,,	58	—	—	—	
½″ diam., soft, black	P_2	28	24	4·3	2·9	69
Up to 1″ diam., black and greyish yellow..	,,	58	53	5·9	2·2	39
½″–¼″ diam., black and greyish yellow, soft..	,,	59	56	4·8	0·9	38
Up to 1″, greyish yellow, no black staining..	S_2	69	66	5·4	Nil	28

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C. A. HAWKINS.

EROSION SURFACES AROUND ARMIDALE, N.S.W.

By A. H. VOISEY, D.Sc.

Department of Geology, The University of New England, Armidale, N.S.W.

With Plate II and one Text-figure.

This paper deals with the physiographical evolution of some 4,000 square miles of country in the neighbourhood of the city of Armidale which lies 343 miles by rail north of Sydney, New South Wales. It lies across the Main Divide of eastern Australia and includes part of the escarpment which is regarded as the eastern boundary of the New England Plateau. Westward it embraces portions of the catchments of some of the tributaries of the Gwydir River. The remainder is drained by the Macleay except for some streams in the north which flow into the Clarence River. The Bellinger River heads at Point Lookout.

This area was taken as a representative strip across the New England Plateau in the hope that detailed study of it would solve some of the problems which had faced those who had visited New England in the past and attempted to work out its history. It is intended in another paper to extend the findings of this survey to the whole of the New England Region.

Previous Literature. Comprehensive descriptions of much of the New England Plateau were given by E. C. Andrews in his papers of 1903 and 1904 and he made references to it in 1906, 1910, 1914 and 1933. F. A. Craft (1933) and C. A. Cotton (1949) emphasized the part played by differential erosion in the development of land-forms. The present writer has already discussed the nature of the pre-basalt surface in southern New England (Voisey, 1942).

Methods of Study. Recognising that there were a number of erosion surfaces to be sorted out and explored an attempt was made to reconstruct them and to determine the nature of the inequalities on each. In the absence of any contour maps it was not possible to use statistical methods. Aerial photographs were obtained and the whole area was examined by means of the stereoscope as well as in the field.

The method of approach differed in the case of each surface.

Form lines of the surface on which the basalt was poured out were obtained by measuring the heights of basalt residuals and intermediate points. Further information as to its character was determined from the examination of the sedimentary deposits which lay upon it. The fossil content of these also received detailed attention.

The original basalt surface has been destroyed by erosion but some slight idea of its main features has been deduced from the examination of high residuals and present drainage patterns.

An old and well developed surface which now remains only in patches along the line of the Main Divide has been recognized from its land-forms and its soils. From the soil-profiles, now partly destroyed, it has been called the Laterite Surface.

The land-forms assist in the recognition of another erosion surface cut out of the Laterite Surface but which itself has been attacked by vigorous streams of a still later cycle.

Some idea of the amounts of the successive uplifts between the development of each surface and which have led to the production of the terraces giving a " wedding cake " effect to the topography has been obtained by considering the average heights as well as the lowest points on them.

Within the confines of the Armidale area alone close determinations of the geological age of each surface have not been possible but some suggestions have been made by correlating on the basis of the plant fossils and other characteristics of the surfaces with those elsewhere and by taking account of the views of other observers in these places.

The surfaces will now be discussed in turn.

Pre-basalt Surface. The writer (Voisey 1942) has already submitted a form-line map of the pre-basalt surface in southern New England which embraces the area now under discussion. This revealed the important fact that inequalities on this surface amounted to over 1,400 ft. immediately before the basalt covered it. It also showed that there was an elongated depression extending from Armidale eastwards to beyond Wollomombi. It is within this and at approximately 3,400 feet above present sea level that lake deposits lie (Voisey 1942, p. 83). Outside the depressed area the basalt lies directly on old rock or soil derived therefrom except where it has covered the deep leads. It is thought that the auriferous gravels of Rocky River near Uralla were deposited by streams flowing into what has been called the " Armidale Lake " (Voisey 1942, p. 84).

The buried valleys of the Guyra area fall southwards towards the lake. Thus, while the basalts occur in flat-topped mesa-like forms, sometimes showing terracing, and overlying the lake sediments around Armidale, they are frequently found at lower levels than the granites which had formed interfluves between the former streams near Chandler's Peak and east and west of Guyra.

The positions of some of the main pre-basalt divides may be determined by careful examination of the form-line map. These vary from those of the present surface—a good example being the ridge running from Day's Mountain to the Round Mountain. This was the parting of the waters of the ancestral Clarence and Macleay Rivers (Voisey 1946).

The lake sediments comprise conglomerates, grits and sandstones which are overlain by a thin band of ferruginous cherty shales containing abundant well preserved plant remains. M. J. Slade (unpublished B.Sc. Honours Thesis, 1951) determined the following mainly from the study of leaves :

Nothofagus Sp.
Cryptocarya cinnamomifolia.
Alectryon subcinereus.
Croton phebaloides, F.v.M.
Elattoctachys nervosa, Radlk.
Litsœa dealbata.
Agathis sp.
Podocarpus spinulosa, R.Br.
P. prœcupressina, E.H. cf. *P. alpina,* R.Br.
Greissos Benthami.
Ceratopetalum sp.
Ficus stephanocarpa, F.v.M·
Palm (indet.).

On the advice of the writer he extracted pollen from the sediments and using the method described by Erdtman (1943) he determined the presence of the *Æratopetalum* and *Nothofagus* together with members of the following families which he determined as Fagaceæ, Ceratophyllaceæ, Myrtaceæ, Lycopodiaceæ, Caryophyllaceæ, Betulaceæ together with some Gymnospermæ.

Slade suggested after a study of the literature that the flora was probably Upper Eocene or Lower Oligocene in age.

Basalt Surface. It is unlikely that any actual part of the top portion of the basalt covering still remains in the area. Some of the highest points e.g. Point Lookout and Chandler's Peak are residuals of basalt flows and not plugs. Obviously, higher areas from which these flows moved must have existed at the time.

The early flows must have followed valleys damming them and diverting some of the streams. Later deluges of lava swept over even the interfluves and buried almost the whole of the Armidale area. Under such circumstances there must have been a great change in the drainage patterns.

It was this " Basalt Surface "—the hypothetical top of the succession of flows—which really determined the present drainage pattern. The way in

SKETCH SECTION THROUGH ARMIDALE TO HILLGROVE
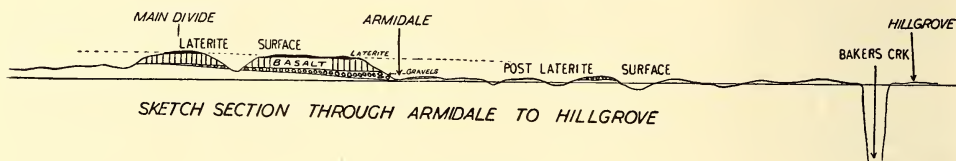
Text-fig. 1.

which the streams cross the grain of the country (e.g. Dumaresq Creek east of Armidale which runs at right angles to meridional ridges of quartzite and jasper) indicates that they have been superimposed upon the older rocks.

The remarkable continuity of the lake deposits and the fact that the thin band of plant remains is so frequently found immediately below the basalt is evidence of the approximate age of the lavas. It is impossible for the time interval to have been long or the plant bed must have been removed by erosion. The question arises as to whether there might not have been an earlier flow which caused the damming of a stream to form the lake in the first instance. No evidence bearing on this matter has so far been found. That there was some erosion was shown by the work of Slade (B.Sc. Hons. Thesis) who found basalt 200 feet below the top horizon of the sediments and actually traced it from this low level up to the top of the leaf horizon.

The igneous rocks then may be tentatively regarded as Oligocene in age.

The Laterite Surface. The " Laterite Surface ", as we may call it, is the most gentle recognized in New England. It has been carved out of basalts and other rocks alike following what must have been a very long period of erosion. Most of the remaining portions of the basalt are associated with this surface which only remains undissected in the vicintiy of the Main Divide and major interfluves.

While the surface can be recognized by its form it is also characterized by the presence of laterite soil profiles in some places and by a much broken laterite in others. So far as the writer can ascertain, after many years studying these surfaces, true laterites in New England are restricted to this surface. However, much of the " ironstone gravel " on it is only the remains of what was once a fuller profile.

SCALE

MILES

0   2   4   6   8

OR.

POINT
LOOKOUT

MN.

BUND

CREEK

FIVE DAY

STOCKYARD CRK.

LEGEND

LIMIT OF RECE
EROSION

LIMIT OF LATE
TERTIARY EROS

BASALT

SWAMPS

MAIN DIVIDE

AROUND ARMIDALE

EROSION SURFACES AROUND ARMIDALE

LEGEND

LIMIT OF RECENT EROSION

LIMIT OF LATE TERTIARY EROSION

BASALT

SWAMPS

MAIN DIVIDE

SCALE

MILES

0   2   4   6   8
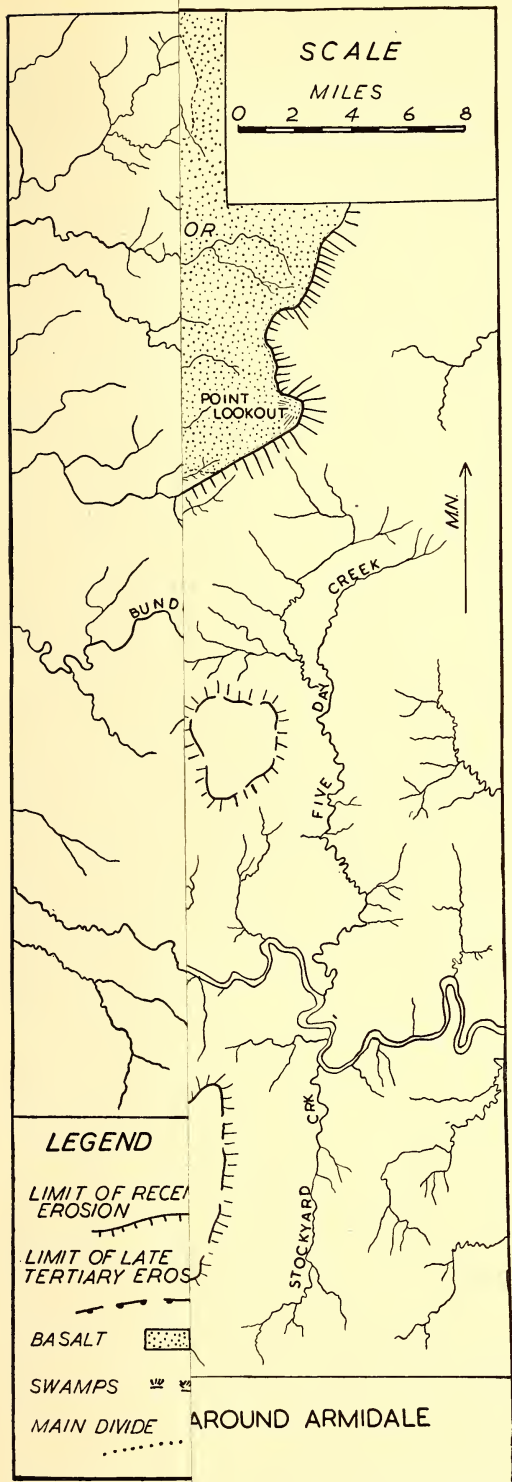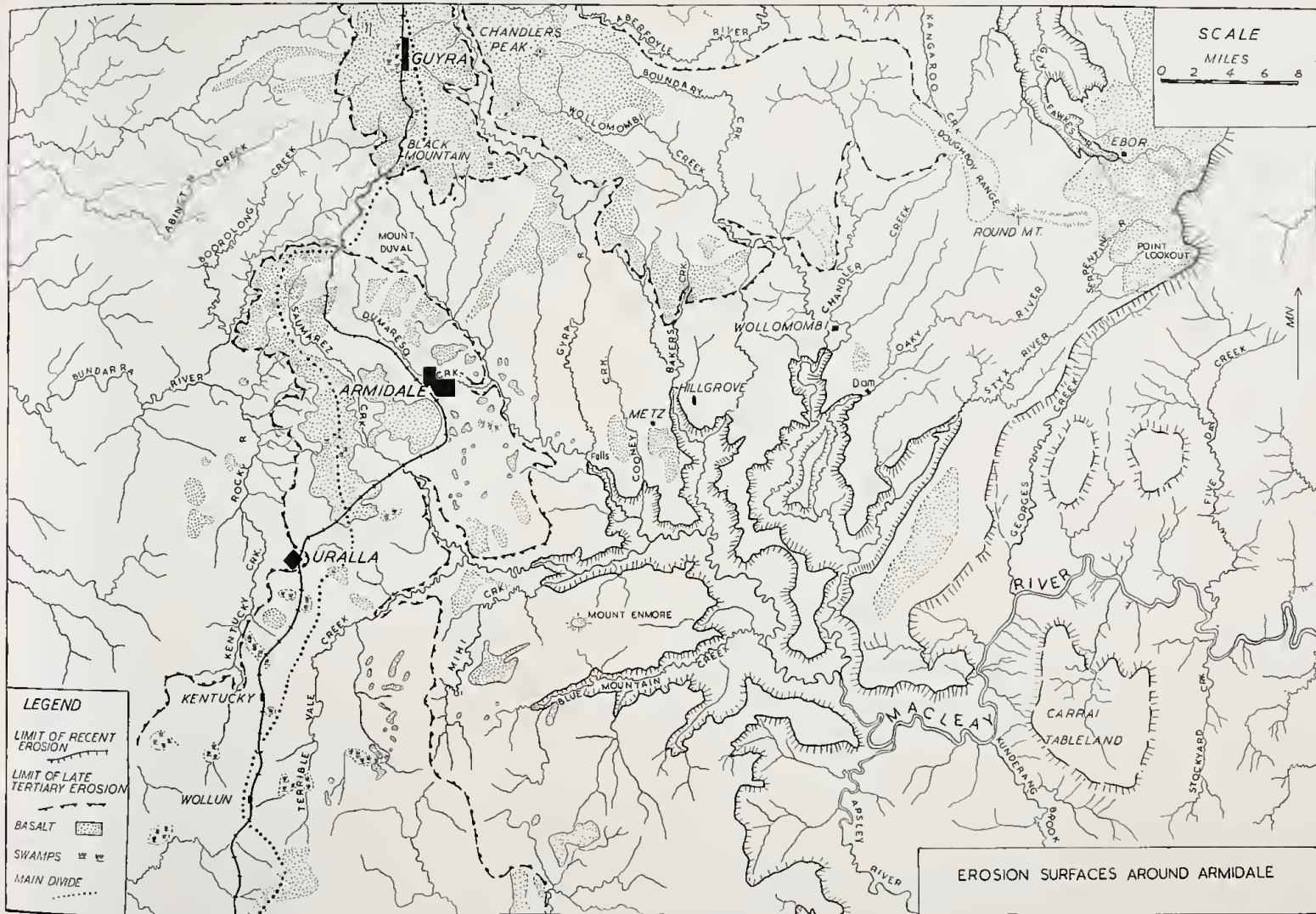
" Ironstone gravel " and laterite-like material may occur on a lower surface but the pallid and mottled zones are never present. According to Jessup (verbal communication) the deposits have been derived from the laterite profiles at higher levels and have been washed down into the valleys. One belt of " ironstone " up to several feet thick runs almost continuously through Armidale from the vicinity of the University of New England to the Racecourse along the southern side of the valley of Dumaresq Creek.

A further criterion assisting in the recognition of this surface is the presence of swamps and lagoons, the largest being " Mother of Ducks " at Guyra. The Main Divide in places is hard to define in this remarkably level country. It is this Laterite Surface which is mainly responsible for the even sky-lines which are so conspicuous from some places in Southern New England.

The surface rises gradually along the line of the Main Divide from about 3,500 feet above sea level between Uralla and Armidale to over 4,000 feet at Guyra. It has been breached by streams near Black Mountain.

Andrews (1910 p. 478) regarded the Guyra-Ben Lomond block as having been uplifted by some hundreds of feet at the end of Tertairy time. As shown previously (Voisey 1942, p. 84) the Pre-Basalt Surface was also high in this area and streams flowed south from it into the Armidale Lake.

If the upwarping or up-faulting in Post-Laterite time is accepted and restoration of the Pre-Basalt Surface is then made it will be seen that these streams must have been flowing up-hill to empty into the lake !

Though there may have been a little upwarping it would appear that the Laterite Surface—though flattish—had risen towards Guyra even in Tertiary times.

The Post-Laterite Surface. Dissection of the Laterite Surface can be recognized from the fact that there is usually a sharp break of slope from the flat land on either side of the Main Divide. Outliers of laterite cap hills rising above a lower and rougher surface. In the field it is in places difficult to determine the exact boundary between the surfaces but an attempt has been made to do so, results being indicated on the accompanying map (Plate II). Outside the areas encircled by the boundary lines are ridges just below the Laterite Surface but which have been lowered to the extent that they must now be considered as belonging to the later and lower surface. Some of these may be capped with gravel or basalt or both.

The suggestion that there was an earth movement post-dating the formation of the laterite and preceding the Kosciusko Epoch (Andrews, 1910) is not new having been put forward by Jensen (1912, p. 188) and later by Andrews (1933). The maximum amount of the uplift ascribed to this movement seems to have been of the order of about 500 ft. along the line of the Main Divide.

The Kosciusko Epoch. The erosion which followed the elevation of the New England Plateau produced a network of steep-sided gorges which cut into its eastern margin. These can be picked out easily on the map (Plate II) and there is no doubt about the separation of the post-Tertiary erosional effects from those which produced the Post-Laterite surface. Streams flowing over the latter, plunge suddenly over falls into the gorges. Andrews (1910, p. 126, footnote) gave the name Kosciusko Epoch to the major uplift of late Tertiary time. There is no absolute indication of the age of the movement but in the absence of any other criterion it is generally taken to separate Tertiary from Pleistocene events.

The aggregate movement assigned to it so far as the Armidale area is concerned appears to have been about 1700 feet. A further amount of about 500 feet is believed to have been added during late or middle Pleistocene times

as indicated by the high deposits of ridge gravel in the valleys of coastal rivers (Voisey, 1934).

The total amount of uplift since early Tertiary times is thought to be of the order of about 2,700 feet made up as follows :

Post Laterite	500 feet.
Kosciusko Uplift	1700 feet.
Post Kosciusko	500 feet.
Total	2700 feet.

These are maximum values applicable only in the vicinity of the Main Divide, they decrease rapidly eastward and slowly to the west.   The high points on the plateau may be explained :

(a) by their being residuals on the older surface and, being some distance inland, there would be a natural fall of the country seawards and

(b) by the thick layers of basalt which were laid upon the older surface.

Recent Surface.   The most striking topographical features of the area are the spectacular gorges and escarpments so well described by Andrews (1903 and 1904).   These have been cut by fluvial agencies since the Kosciusko Uplift. Waterfalls at the heads of most gorges mark the limit of upstream cutting. Below them incised meanders are a feature of the topography.   The steep slopes in places are bare of soil and talus and fall abruptly from the gently undulating older surface.

CONCLUSION.

An attempt has been made to separate the erosion surfaces of the Armidale area.   The continued existence of the Laterite Surface probably from Miocene times until the present day shows that, even in areas subjected to fluvial erosion, plateaus are reduced by the inward retreat of their margins—not by a gradual lowering of the whole surface.

ACKNOWLEDGEMENTS.

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A NOTE ON TWO DIMENSIONAL FOURIER TRANSFORMS.

By J. L. Griffith.

School of Mathematics, New South Wales University of Technology.

Summary.

Assuming that the two-dimensional Fourier Transform of a function $w(x,y)$ is given by

$$F_2[w(x,y)] \equiv \bar{w}(\xi,\eta)$$

$$= \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} e^{i(\xi x + \eta y)} w(x,y) dx dy$$

and that $\rho^2 = \xi^2 + \eta^2$, it is shown that

$$F_2^{-1}\left[\frac{e^{-a\rho}}{\rho} \cdot \bar{w}(\xi,\eta)\right] = -\frac{1}{2\pi} \int_{\infty}^{0(a)} \int_0^{2\pi} \frac{z}{(z^2+a^2)^{\frac{1}{2}}} w(x - z\cos\theta, \ y - z\sin\theta) d\theta dz$$

where it is understood that the contour, on which the integral $\int_{\infty}^{0(a)} \ldots dz$ is taken, starts at $+\infty$ on the real axis and terminates at the origin with $\arg z = \arg a$, without crossing the interval $(ai, -ai)$.

Similar formulæ are given for $F_2^{-1}[e^{-a\rho}\bar{w}(\xi,\eta)]$

$$F_2^{-1}[\rho^{-1}\sinh a\rho \cdot \bar{w}(\xi,\eta)], \quad F_2^{-1}[\rho^{-1}\cosh a\rho \cdot \bar{w}(\xi,\eta)]$$

$$F_2^{-1}[\sinh a\rho \cdot \bar{w}(\xi,\eta)], \quad F_2^{-1}[\cosh a\rho \cdot \bar{w}(\xi,\eta)]$$

and

$$F_2^{-1}[\rho^\nu K_\nu(a\rho) \cdot \bar{w}(\xi,\eta)].$$

1.

The two-dimensional Fourier Transform, used in this note, is that defined in the form

$$F_2[w(x,y)] \equiv \bar{w}(\xi,\eta)$$

$$= \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} e^{i(\xi x + \eta y)} w(x,y) dx dy. \quad \ldots\ldots\ldots (1.1)$$

It will be assumed, throughout, that $w(x,y)$ is continuous in both x and y, and that the integral in equation (1.1) converges absolutely. Then, the transform has the inverse

$$F_2^{-1}[\bar{w}(\xi,\eta)] \equiv w(x,y)$$

$$= \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} e^{-i(\xi x + \eta y)} \bar{w}(\xi,\eta) d\xi d\eta. \quad \ldots\ldots (1.2)$$

This integral will not be used directly. It will suffice to know that a unique inverse does exist.

The convolution formula associated with this transform is

$$F_2^{-1}[\bar{w}(\xi,\eta) \cdot \bar{v}(\xi,\eta)] = \frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} w(x-p, y-q)v(p,q)dpdq \quad .. \quad (1.3a)$$

$$= \frac{1}{2\pi}\int_0^{\infty}\int_0^{2\pi} w(x-r\cos\varphi, y-r\sin\varphi)v(r\cos\varphi, r\sin\varphi)rd\varphi dr.$$

$$\dots \dots \dots \dots \dots (1.3b)$$

It is well known that if $w(x,y) \equiv w(R)$ where $R^2 = x^2 + y^2$ then $\bar{w}(\xi,\eta) \equiv \bar{w}(\rho)$ where $\rho^2 = \xi^2 + \eta^2$ and that equations (1.1) and (1.2) reduce to

$$\bar{w}(\rho) = \int_0^{\infty} RJ_0(\rho R)w(R)dR \dots \dots \dots \dots (1.4)$$

and

$$w(R) = \int_0^{\infty} \rho J_0(\rho R)\bar{w}(\rho)d\rho \dots \dots \dots \dots (1.5)$$

$J_0(t)$ being the Bessel Function of the first kind of order zero.

In [G], formulæ for $F_2^{-1}[\rho^{-1}\sin a\rho \cdot \bar{w}(\xi,\eta)]$, $F_2^{-1}[\rho^{-1}\sinh a\rho \cdot \bar{w}(\xi,\eta)]$, $F_2^{-1}[\cos a\rho \cdot \bar{w}(\xi,\eta)]$ and $F_2^{-1}(\cosh a\rho \cdot \bar{w}(\xi,\eta)]$ were derived on the assumption that a was real. The first only of these formulæ was a direct consequence of the convolution formula.

In this note, formulæ for $F_2^{-1}[e^{-a\rho} \cdot \bar{w}(\xi,\eta)]$ and $F_2^{-1}[\rho^{-1}e^{-a\rho} \cdot \bar{w}(\xi,\eta)]$ will be derived. These formulæ will hold for all a, real or complex, and will appear in the form of equation (1.3b). However, there will be a fundamental difference : the outer integral will be a contour integral in the complex plane. From these formulæ it will be possible to derive the formulæ for the inverses quoted in the preceding paragraph. These formulæ will, of course, hold for all a.

The following notations will be used :

(i) $w(x-z\cos\theta, y-z\sin\theta) \equiv W(z, \theta)$; $\dots \dots \dots \dots \dots (1.6)$

(ii) when a contour integral is written in the form

$$\int_{A(a)}^{B(b)} f(z)dz, \quad \dots \dots \dots \dots \dots \dots \dots \dots (1.7)$$

it will be understood that the contour starts at A with arg $z = $ arg a and terminates at B with arg $z = $ arg b.

<center>2.</center>

From the well-known result

$$\int_0^{\infty} e^{-a\rho}J_0(z\rho)d\rho = (z^2+a^2)^{-\frac{1}{2}} \quad \dots \dots \dots (2.1)$$

which holds for $\mathrm{Re}\, a \geqq 0$ we obtain from equation (1.5)

$$\int_0^{\infty} z(z^2+a^2)^{-\frac{1}{2}}J_0(\rho z)dz = \rho^{-1}e^{-a\rho}. \quad \dots \dots \dots (2.2)$$

Both integrals in equations (2.1) and (2.2) are taken along the real axis, and the branch of $(z^2+a^2)^{-\frac{1}{2}}$ is that on which $(z^2+a^2)^{-\frac{1}{2}}$ is positive for a real.

To generalize the result in (2.2), we consider the contour integral

$$\int_{\infty}^{0(a)} z(z^2+a^2)^{-\frac{1}{2}}J_0(\rho z)dz \equiv Q(a,\rho) \quad \ldots\ldots\ldots (2.3)$$

in which, we understand that

      (i) the complex z-plane has a cut: the interval joining the points ai and $-ai$. This cut will be called B.

      (ii) $(z^2+a^2)^{\frac{1}{2}} \equiv (z+ia)^{\frac{1}{2}}(z-ia)^{\frac{1}{2}}$ where $\arg(z+ia)^{\frac{1}{2}}$ and $\arg(z-ia)^{\frac{1}{2}}$ are both zero at $z=+\infty$.

     (iii) $|a|>A>0$.

The restrictions (i)-(iii) indicate that $Q(a,\rho)$ is an analytic function of a, for all $|a|>A>0$. When $-\frac{1}{2}\pi<\arg a<\frac{1}{2}\pi$, the path of integration may be distorted to coincide with the real axis, and then equation (2) shows that

$$Q(a,\rho)=-\rho^{-1}e^{-a\rho},$$

from which we conclude that

$$\int_{\infty}^{0(a)} z(z^2+a^2)^{-\frac{1}{2}}J_0(\rho z(dz=-\rho^{-1}e^{-a\rho}$$

for all $|a|>A>0$.

We have thus proved

Lemma 2.1.

If (i)-(iii) of this section hold, then

$$\int_{\infty}^{0(a)} z(z^2+a^2)^{-\frac{1}{2}}J_0(\rho z)dz=-\rho^{-1}e^{-a\rho}. \quad \ldots\ldots\ldots (2.4)$$

Before using this lemma, we see that $e^{-a\rho}$ is a single valued function of a. This will allow the terminal condition to be relaxed. We will merely require that

$$\arg z=\arg a+2n\pi \qquad (n, \text{integral}), \quad \ldots\ldots (2.5)$$

and an examination of the integrand allows a further relaxation of the terminal condition to

$$-\frac{1}{2}\pi<\arg z-\arg a-2n\pi<\frac{1}{2}\pi, \qquad (n, \text{integral}). \quad \ldots\ldots (2.6)$$

Also for $\rho>0$, $|J_0(\rho z)|=O(|z|)^{-\frac{1}{2}})$ as $\operatorname{Re} z\to\infty$ then equation (2.4) may be replaced by

$$\int_{iy+\infty}^{0(a)} z(z^2+a^2)^{-\frac{1}{2}}J_0(\rho z)dz=-\rho^{-1}e^{-a\rho} \quad \ldots\ldots (2.7)$$

for finite y.

Direct integration shows that equation (2.4) also holds for $a=0$.

We now prove

Theorem 2.1.

If

    (i) $w(u,v)$ is analytic in both u and v in the region $|\operatorname{Im} u|<b$, $|\operatorname{Im} v|<b$;

    (ii) If the assumptions of Lemma 2.1 hold;

(iii) as $\operatorname{Re} u \to \pm\infty$ and $\operatorname{Re} v \to \pm\infty$ in the region of (i) $w(u,v) \to 0$ in such a way that

$$F_2[w(x,y)] = \bar{w}(\xi,\eta)$$

and

$$\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{\infty}^{0(a)} \int_{0}^{2\pi} z(z^2+a^2)^{-\frac{1}{2}} W(z,\theta) d\theta dz dx dy$$

converge absolutely ;

(iv) $|\operatorname{Im} a| < b$ and the z-contour in the multiple integral above does not pass outside the region $|\operatorname{Im} z| < b$, then

$$F_2\left[\frac{1}{2\pi} \int_{\infty}^{0(a)} \int_{0}^{2\pi} z(z^2+a^2)^{-\frac{1}{2}} W(z,\theta) d\theta dz\right]$$

$$= -\rho^{-1} e^{-a\rho} \bar{w}(\xi,\eta). \quad \dots\dots\dots\dots\dots\dots (2.8)$$

Proof.

$$\frac{1}{4\pi^2} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{\infty}^{0(a)} \int_{0}^{2\pi} z(z^2+a^2)^{-\frac{1}{2}} W(z,\theta) e^{i(\xi x + \eta y)} d\theta dz dx dy$$

$$= \frac{1}{4\pi^2} \int_{\infty}^{0(a)} \int_{0}^{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} z(z^2+a^2)^{-\frac{1}{2}} W(z,\theta) e^{i(\xi x + \eta y)} dx dy d\theta dz$$

(by absolute convergence)

$$= \frac{1}{4\pi^2} \int_{\infty}^{0(a)} \int_{0}^{2\pi} \int_{z \sin\theta - \infty}^{z\sin\theta + \infty} \int_{z\cos\theta - \infty}^{z\cos\theta + \infty} z(z^2+a^2)^{-\frac{1}{2}} e^{iz(\xi\cos\theta + \eta\sin\theta)} e^{i(\xi p + \eta q)} w(p,q) dp dq d\theta dz$$

(putting $x = p + z\cos\theta$ and $y = q + z\sin\theta$)

$$= \frac{1}{4\pi^2} \int_{\infty}^{0(a)} \int_{0}^{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} z(z^2+a^2)^{-\frac{1}{2}} e^{iz\rho\cos(\theta - \alpha)} e^{i(\xi p + \eta q)} w(p,q) dp dq d\theta dz$$

(using the first part of (iii) above to change the p- and q-paths to the real axes, and putting $\tan a = \eta/\xi$)

$$= \frac{1}{2\pi} \int_{\infty}^{0(a)} z(z^2+a^2)^{-\frac{1}{2}} J_0(z\rho) \bar{w}(\xi,\eta) dz$$

$$= -\rho^{-1} e^{-a\rho} \bar{w}(\xi,\eta).$$

Now

$$F_2[\rho^{-1} \sinh a\rho \cdot \bar{w}(\xi,\eta)] = F_2[(2\rho)^{-1}(e^{a\rho} - e^{-a\rho}) \bar{w}(\xi,\eta)]$$

$$= -\frac{1}{4\pi} \left[\int_{\infty}^{0(-a)} - \int_{\infty}^{0(a)} \right] \int_{0}^{2\pi} z(z^2+a^2)^{-\frac{1}{2}} W(z,\theta) d\theta dz$$

which gives

Theorem 2.2a.

If the assumptions of Theorem 2.1 hold, then

$$F_2^{-1}[\rho^{-1} \sinh a\rho \cdot \bar{w}(\xi,\eta)] = \frac{1}{4\pi} \int_{0(-a)}^{0(a)} \int_{0}^{2\pi} z(z^2+a^2)^{-\frac{1}{2}} W(z,\theta) d\theta dz \qquad (2.9)$$

This may be written in the form of [G] §2.

Theorem 2.2b.

If the assumptions of Theorem 2.1 hold, then

$$\left[\frac{\sin a \,\nabla}{\nabla}\right]w(x,y)=\frac{1}{4\pi}\int_{0(-a)}^{0(a)}\int_0^{2\pi} z(z^2+a^2)^{-\frac{1}{2}}W(z,\theta)d\theta dz \quad \text{....} \quad (2.10)$$

where ∇^2 stands for the operator $\dfrac{\partial^2}{\partial x^2}+\dfrac{\partial^2}{\partial y^2}$.

By distorting the path of the z-integral till it coincides with the cut B, the right side of equation (2.9) may be written as

$$\frac{1}{2\pi}\int_{0(-a)}^{\pm ai}\int_0^{2\pi} z(z^2+a^2)^{-\frac{1}{2}}W(z,\theta)d\theta dz \quad \text{.........} \quad (2.11a)$$

or

$$\frac{1}{2\pi}\int_0^{|a|}\int_0^{2\pi}\frac{qe^{i\alpha}}{[|a|^2-q^2]}W(\pm iqe^{i\alpha},\theta)d\theta dq \quad \text{......} \quad (2.11b)$$

(where $a=|a|e^{i\alpha}$).

From equation (2.11a) it is easy to derive

Theorem 2.3.

If the assumptions of Theorem 2.1 hold, then

$$F_2^{-1}[\rho^{-1}\cosh a\rho \,.\, \bar{w}(\xi,\eta)]$$

$$=\frac{1}{2\pi}\int_{\pm ia}^{\infty}\int_0^{2\pi} z(z^2+a^2)^{-\frac{1}{2}}W(z,\theta)d\theta dz \quad \text{........} \quad (2.12)$$

3.

It is easily seen that with the assumptions of Theorem 2.1 we may differentiate equation (2.8) with regard to a to obtain

Theorem 3.1.

If the assumptions of Theorem 2.1 hold, then

$$F_2^{-1}[e^{-a\rho} \,.\, \bar{w}(\xi,\eta)]$$

$$=-\frac{1}{2\pi}\int_{\infty}^{0(a)}\int_0^{2\pi} za(z^2+a^2)^{-3/2}W(z,\theta)d\theta dz \quad \text{........} \quad (3.1a)$$

$$=w(x,y)-\frac{1}{2\pi}\int_{\infty}^{0(a)}\int_0^{2\pi} a(z^2+a^2)^{-\frac{1}{2}}\frac{\partial}{\partial z}W(z,\theta)d\theta dz \quad \text{....} \quad (3.1b)$$

(the second result being obtained by integration by parts).

Proceeding as in the last section, we find

Theorem 3.2.

If the assumptions of Theorem 2.1 hold, then

$$F_2^{-1}[\cosh a\rho \, . \, \bar{w}(\xi,\eta)]=[\cos a \, \nabla]w(x,y)$$

$$=-\frac{1}{4\pi}\int_{0(-a)}^{0(a)}\int_0^{2\pi} za(z^2+a^2)^{-3/2}W(z,\theta)d\theta dz \quad \ldots\ldots\ldots \quad (3.2a)$$

$$=w(x,y)-\frac{1}{4\pi}\int_{0(-a)}^{0(a)}\int_0^{2\pi} a(z^2+a^2)^{-\frac{1}{2}}\frac{\partial}{\partial z}W(z,\theta)d\theta dz \quad \ldots\ldots \quad (3.2b)$$

$$=w(x,y)+\frac{1}{2\pi}\int_0^{|a|}\int_0^{2\pi}\frac{|a|}{[|a|^2-q^2]^{\frac{1}{2}}}\frac{\partial}{\partial q}W(\pm iqe^{ia},\theta)d\theta dq \quad \ldots \quad (3.2c)$$

and

$$F_2^{-1}[\sinh a\rho \, . \, \bar{w}(\xi,\eta)]$$

$$=\frac{1}{4\pi}\int_\infty^{\pm ai}\int_0^{2\pi} a(z^2+a^2)^{-\frac{1}{2}}\frac{\partial}{\partial z}W(z,\theta)d\theta dz \quad \ldots\ldots \quad (3.3)$$

4.

A similar generalization can be developed from

$$\int_0^\infty z(z^2+a^2)^{-1}J_0(\rho z)dz=K_0(a\rho), \quad \text{Re } a>0 \quad \ldots\ldots\ldots \quad (4.1)$$

(see [W.B.F.], p. 425 (5)). This leads to

$$\int_\infty^{0(a)} z(z^2+a^2)^{-1}J_0(\rho z)dz=-K_0(a\rho) \quad \ldots\ldots\ldots\ldots \quad (4.2)$$

In this integral, we must not allow equations (2.5) or (2.6) to hold, but must restrict the meaning of $0(a)$ to that given in line (1.7).

After making suitable restrictions on $w(x,y)$, we may derive

$$F_2^{-1}[K_0(a\rho) \, . \, \bar{w}(\xi,\eta)]$$

$$=-\frac{1}{2\pi}\int_\infty^{0(a)}\int_0^{2\pi} z(z^2+a^2)^{-1}W(z,\theta)d\theta dz \quad \ldots\ldots \quad (4.3)$$

More generally, using [H.T.F.], p. 24 (20) we find

$$F_2^{-1}[\rho^\nu K_\nu(a\rho) \, . \, \bar{w}(\xi,\eta)]$$

$$=-\frac{1}{2\pi}\int_\infty^{0(a)}\int_0^{2\pi}\frac{2^\nu\Gamma(\nu+1)a^\nu}{(a^2+z^2)^{\nu+1}}W(z,\theta)d\theta dz \quad \ldots\ldots \quad (4.4)$$

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THE THIRD DISSOCIATION CONSTANT OF THE TRIS–ACETYLACETONE COMPLEXES WITH BIVALENT METALS

By F. P. Dwyer, D.Sc.,
and A. M. Sargeson, B.Sc.

Abstract.

The third dissociation constant, K_3, for the complex anion $(M(aca)_3)'$, (M=Ni, Co, Fe, Zn, Mg, Mn) in 80% dioxan solution has been found to be nearly identical for all the complexes examined. The value $pK_3 = \sim 6$ leads to the conclusion that extensive dissociation of the third acetylacetone residue would occur in aqueous solution.

The first and second dissociation constants for the bis-acetylacetone complexes of the bivalent metals, Be, Mg, Mn, Fe, Co, Ni, Cu, Zn and Cd, have been measured in aqueous solution and various concentrations of dioxan in water by several workers (Calvin and Wilson, 1945; Mellor and Maley, 1947; van Uitert, Fernelius and Douglas, 1953). The isolation of the sodium and potassium salts Na or $K[M^{II} (aca)_3]$, M^{II} Co, Ni, Mn, Fe, Zn, Cd and Mg (Dwyer and Sargeson, 1956) has made a knowledge of the third constant desirable. Evidence has been advanced that the tris complexes are not merely stoichiometric mixtures of the bis compounds $[M (aca)_2]°$ and the alkali metal acetylacetonate, but loss of the third ligand appears to be facile.

The method of measurement used was essentially that of Calvin and Wilson, (1945), but a higher concentration of dioxan ($\bar{x} = 0.48$) was necessary in order to obtain reproducible results and the usual accuracy of ± 0.05 pK units. Independent studies (Dwyer and Sargeson, 1955) have shown that exchange between the ligands and the various metal complexes occurs in the time of mixing. As a result the pH titration curves could be obtained rapidly without the necessity of employing catalysts such as charcoal.

The equilibria involved in the formation of the tris complexes can be represented:

$$Me^{2+} + Ke' \rightleftarrows [MeKe]^+$$
$$[MeKe]^+ + Ke' \rightleftarrows [MeKe_2]°$$
$$[MeKe_2]° + Ke' \rightleftarrows [MeKe_3]'$$
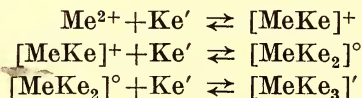
From the above equilibria it can be deduced:

$$T_{Me} = Me^{2+} + [MeKe]^+ + [MeKe_2]° + [MeKe_3]'$$

and

$$T_{HKe} = HKe + Ke' + [MeKe]^+ + 2[MeKe_2]° + 3[MeKe_3]'$$

where T_{Me} = Total metal ion concentration.

HKe = Concentration of undissociated ligand.

Ke' = Concentration of ligand ion.

K

Similarly, by summing the charged species it is found that

$$[MeKe]^+ + Na^+ + H^+ + 2Me^{2+} = ClO_4' + OH' + Ke' + [MeKe_3]'$$

and

$$2T_{Me} + A = ClO_4'$$
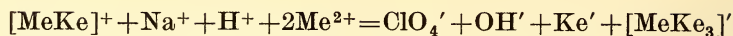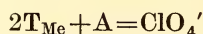
where A = concentration of perchloric acid, K_d is the dissociation constant of the ligand, and the other terms refer to the concentrations of the particular ions.

From these equations it is deduced:

$$\bar{n} = \frac{Na^+ + H^+ - A - \dfrac{K_w}{H^+} - \dfrac{K_d}{H^+}\left(T_{HKe} - Na^+ + A - H^+ + \dfrac{K_w}{H^+}\right)}{T_{Me}}$$

and

$$Ke = \frac{K_d}{H^+}\left(T_{HKe} - Na^+ + A - H^+ + \frac{K_w}{H^+}\right).$$

The $\bar{n}$ and pKe values obtained from the pH titration curves and the above expressions were treated by the graphical method of Bjerrum (1941) and the determinant method of Sullivan and Hindman (1952) in order to obtain all three dissociation constants.

TABLE 1.

I. Bjerrum Graphical Method.

Metal.			pK$_1$.	pK$_2$.	pK$_3$.
Ni[II]	..	..	$11\cdot40 \pm 0\cdot05$	$9\cdot30 \pm 0\cdot05$	$6\cdot10 \pm 0\cdot05$
Co[II]	..	..	$11\cdot15$,,	$9\cdot40$,,	$6\cdot15$,,
Zn	..	..	$10\cdot90$,,	$9\cdot55$,,	$6\cdot25$,,
Fe[II]	..	..	$10\cdot85$,,	$8\cdot50 \pm 0\cdot6$	$5\cdot80$,,
Mn[II]	..	..	$9\cdot80$,,	$8\cdot15 \pm 0\cdot05$	$6\cdot10$,,
Mg	..	..	$9\cdot35$,,	$7\cdot85$,,	$6\cdot15$,,
Cd	..	..	$9\cdot25$,,	$7\cdot45$,,	$5\cdot80$,,

II. Sullivan and Hindman's Method.

Metal			pK$_1$	pK$_2$	pK$_3$
Ni[II]	..	..	$11\cdot33 \pm 0\cdot05$	$9\cdot27 \pm 0\cdot05$	$5\cdot99 \pm 0\cdot05$
Co[II]	..	..	$11\cdot10$,,	$9\cdot39$,,	$6\cdot16$,,
Zn	..	..	$10\cdot85$,,	$9\cdot62$,,	$6\cdot26$,,
Fe[II]	..	..	$10\cdot80$,,	$8\cdot8 \pm 0\cdot06$	$5\cdot85$,,
Mn[II]	..	..	$9\cdot72$,,	$8\cdot12 \pm 0\cdot05$	$6\cdot12$,,
Mg	..	..	$9\cdot32$,,	$7\cdot83$,,	$6\cdot10$,,
Cd	..	..	$9\cdot25$,,	$7\cdot37$,,	$5\cdot88$,,

The results are shown in Table 1, and the formation curves in Figure 1. It will be observed that either method of calculation gives substantially the same values for the constants. For comparison, the values of pK$_1$ and pK$_2$ measured by van Uitert *et al.* (1952) ($\bar{x} = 0\cdot38$ for dioxan) are shown in Table 2.

The stability of the complexes, as might be anticipated, is enhanced in the more concentrated dioxan but the general order of stability remains the same :

$$\text{Ni} > \text{Co} > \text{Zn} > \text{Fe} > \text{Mn} > \text{Mg} > \text{Cd}.$$
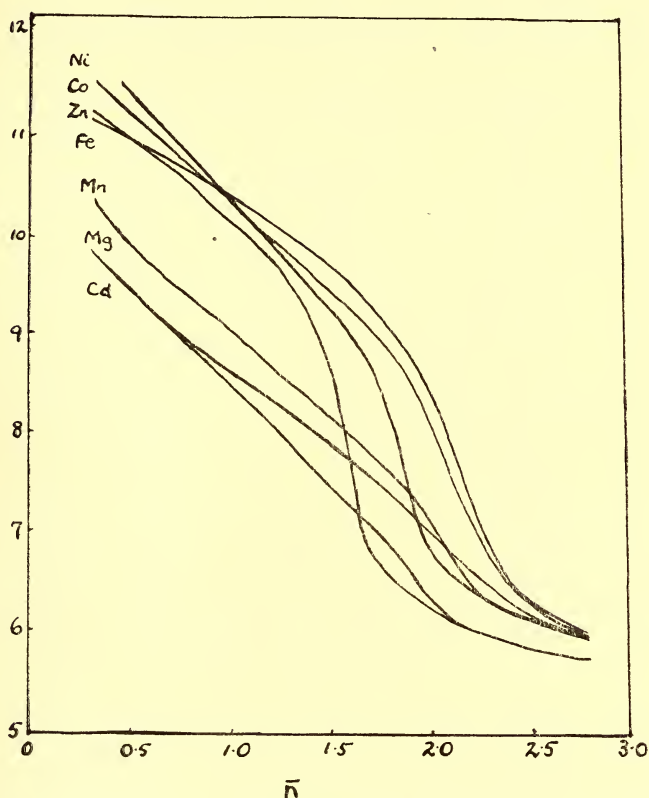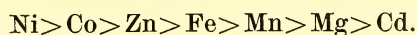
Text-fig. 1.

van Uitert *et al.* (1953) showed that the plot of pK_1 or pK_2 against the mole fraction of dioxan was linear. The linearity is retained when the present values at the higher dioxan concentration are inserted (Figures 2 and 3). It is evident

TABLE 2.
Dissociation Constants at $\bar{n} = 0 \cdot 38$.
(Van Uitert *et al.*, 1953.)

Metal.	pK_1.	pK_2.
Ni^{II}	$10 \cdot 19$	$8 \cdot 21$
Co^{II}	$9 \cdot 68$	$7 \cdot 92$
Zn	$9 \cdot 52$	$8 \cdot 05$
Fe^{II}	$9 \cdot 71$	$8 \cdot 48$
Mn^{II}	$8 \cdot 50$	$6 \cdot 84$
Mg	$7 \cdot 81$	$6 \cdot 09$
Cd	$7 \cdot 64$	$6 \cdot 42$

The perchlorates of the metal were used in each instance except for cadmium, where this ion was replaced by nitrate.

that the linear relationship is dependent only on the composition of the solvent, since the graphs for each element are more or less parallel to the plot of the dissociation constant of acetylacetone itself against the mole fraction of dioxan (Figure 2).

It will be noticed that the third dissociation constant for all of the complexes is approximately 6 pK units. If the trend with the first and second constants
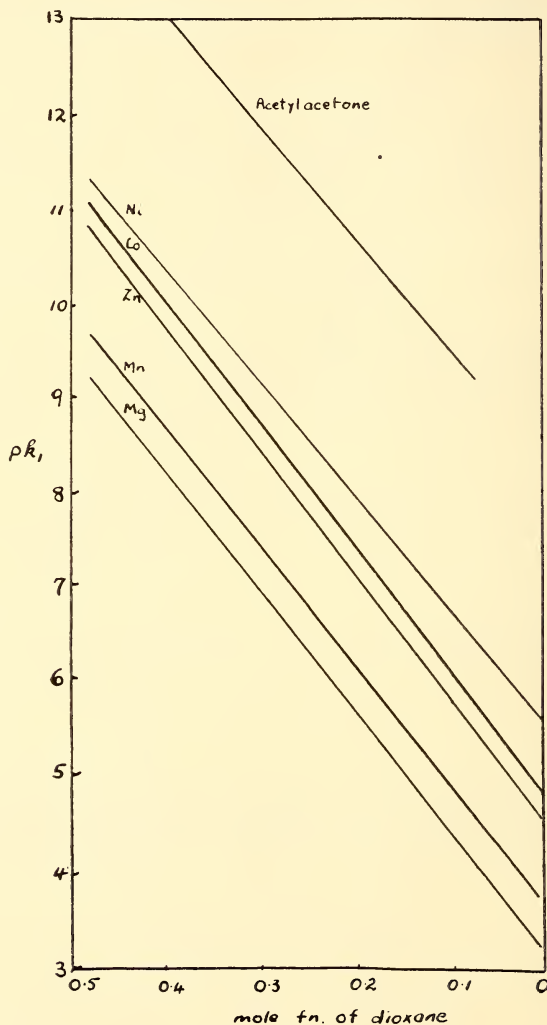
Text-fig. 2.

is followed, as seems reasonable, it can be inferred that in purely aqueous solution $pK_3 \approx 0 \cdot 4$, and hence approximately 50% dissociation would occur. It is therefore not surprising that the existence of the ion $[M^{II} (aca)_3]'$ in aqueous solution should have been unobserved until recently.

Previous workers (van Uitert *et al.*, 1952) have found that the dissociation constants are insensitive to temperature changes. At 20° C. and 50° C. in two dioxan concentrations ($\bar{x} = 0 \cdot 48$ and $0 \cdot 18$) it has been found that the constants

for the nickel complex did not differ beyond the usual experimental reproduc-ability of $\pm 0 \cdot 05$ pK units.   The standard enthalpy change in this temperature range can be regarded as negligible.   If the activity coefficients of the various
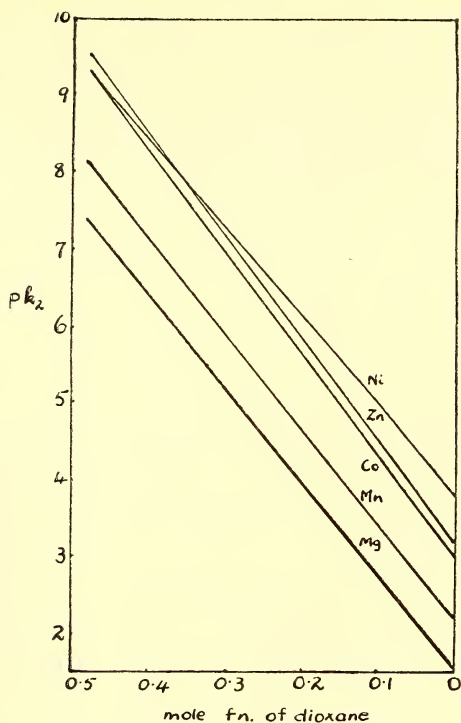
Text-fig. 3.

ionic species are ignored it is possible to make approximate estimates of the entropy changes involved.   The values quoted in Table 3 are of the same order as those for the dissociation of acetic acid in aqueous dioxan solutions (Harned

<div align="center">TABLE 3.</div>

Mole fn. of Dioxan.	pK_1.	$\triangle F°$.	$\triangle S°$ E.U.
		Kcal	
0·48	11·4	15·3$\pm$0·2	—52$\pm$1
0·38	10·2	13·7 ,,	—47 ,,
0·18	10·7	10·3 ,,	—35 ,,
0·00	5·6	7·5 ,,	—26 ,,
	pk_2.	$\triangle F°$.	$\triangle S°$ E.U.
		Kcal	
0·48	9·3	12·5$\pm$0·2	—43$\pm$1
0·38	8·2	11·0 ,,	—38
0·18	5·9	7·9 ,,	—27
0·00	3·8	5·1	—17

and Owen, 1950). It is apparent that, though the dissociation constant decreases with increase in the concentration of the non-polar dioxan, as one would expect, the decrease is almost entirely due to a more negative entropy of ionization.

EXPERIMENTAL.

The titrations were carried out with a Leeds and Northrup pH meter with glass and calomel electrodes. The sodium hydroxide (1·148N) was added from a micro-burette (graduated to 0·01 ml.) to a solution containing acetylacetone ($1·2 \times 10^{-3}$ M), the perchlorate of the metal ($1·00 \times 10^{-4}$ M), perchloric acid (1×10^{-3} M) containing the appropriate amounts of dioxan and water. The perchloric acid was estimated potentiometrically from metal to metal. The mixture was stirred rapidly during the titration, using an atmosphere of nitrogen, and two minutes allowed between the addition of the alkali and the measurement of the pH in order to reach equilibrium.

The dissociation constant of acetylacetone in the particular solvent mixture was determined by the standard titration procedure.

SUMMARY.

The third dissociation K_3 of the $[M^{II}(aca)_3]'$ ion has been determined in 80% dioxan solution for the complexes of a number of bivalent metals. The value $pK_3 = \sim 6$ has been found for all of the metals. It can be inferred that in aqueous solution dissociation of the third acetylacetone residue would occur to the extent of about 50%.

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School of Chemistry,
   University of Sydney.

CLAY MINERALS IN SOME HAWKESBURY SANDSTONES.

By F. C. LOUGHNAN
and H. G. GOLDING.
School of Mining Engineering and Applied Geology, N.S.W. University of Technology.
With Plate III.

ABSTRACT.

The minus two micron fractions from six samples of Hawkesbury Sandstone have been examined by X-ray and differential thermal methods. Illite is the predominant mineral, whilst kaolinite is either absent or present in subordinate amounts. An authigenic origin is suggested for the illite.

INTRODUCTION.

Previous references to clay minerals in the Hawkesbury Sandstones include those by Smith (1891) and Osborne (1948). Osborne recorded the presence of chlorite and kaolinite and made reference to the possible occurrence of illite. In the present study, samples of the minus two micron fractions from six sandstones of the Sydney District have been analysed by differential thermal and X-ray methods.

SAMPLES INVESTIGATED.

The following samples of sandstone were selected for examination, and the minus two micron fractions were obtained by normal sedimentation techniques.

(1) Yellowish, compact, fine grained, sideritic, massive sandstone containing approximately 30% matrix, from Paddington Quarry, Sydney. Upper Hawkesbury.

(2) Grey compact, fine grained, massive sandstone containing approximately 40% matrix, from Gosford Quarry. Lower Hawkesbury (?).

(3) Brown, fine grained rhythmically banded sandstone containing about 40% matrix, Gosford Quarry. Lower Hawkesbury (?).

(4) White, friable, medium grained, massive sandstone containing about 20% matrix from Piles Creek Quarry, near Gosford. Middle Hawkesbury (?).

(5) Grey, compact, fine to medium grained, sideritic, massive sandstone containing approximately 30% matrix, Maroubra Quarry. Upper Hawkesbury.

(6) Pink and white, friable, medium grained, current bedded sandstone with approximately 15% matrix. From a disused quarry, Middle Cove, Sydney. Upper Hawkesbury.

COMPOSITION OF THE CLAY FRACTION.

In Figure 1 the differential thermal curves for the six samples are compared with a standard sample of kaolinite from St. Ives, N.S.W., and one of illite from Fithian, Illinois. All samples display an early small endothermic peak
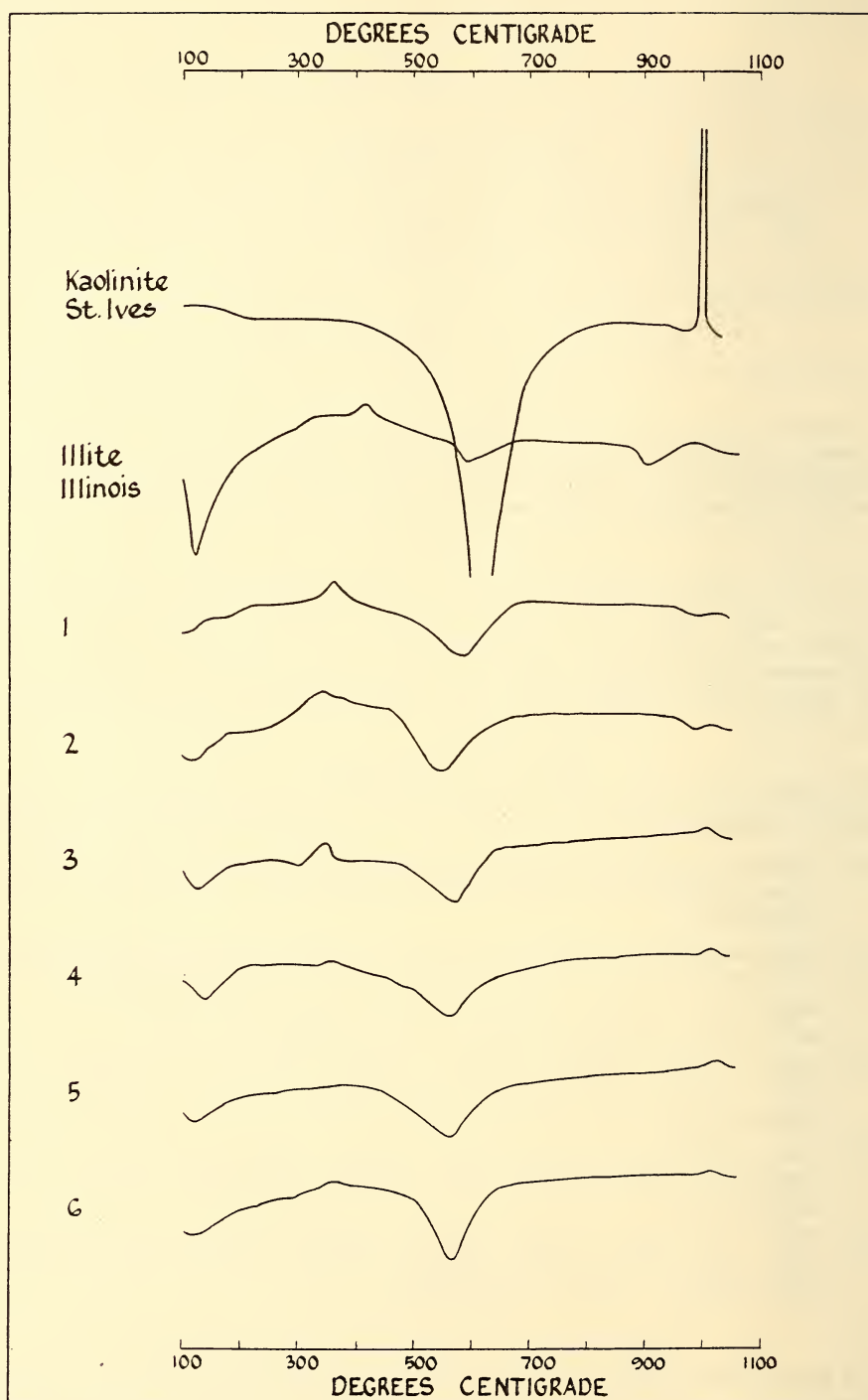
Text-fig. 1.
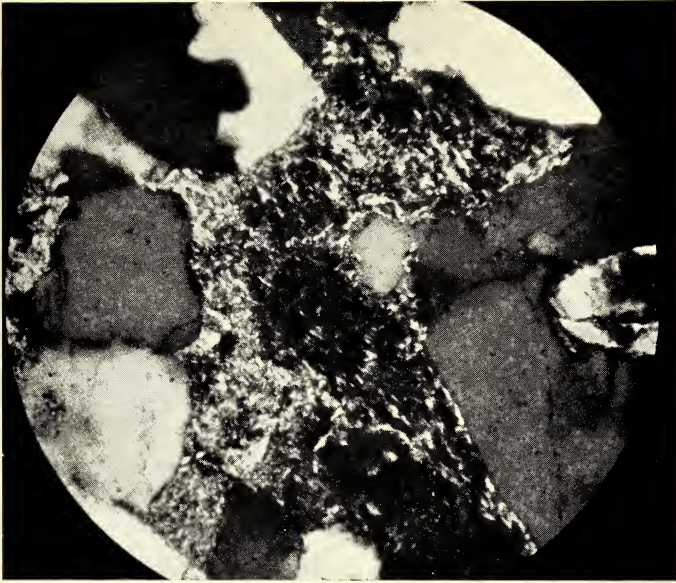
Fig. 1.
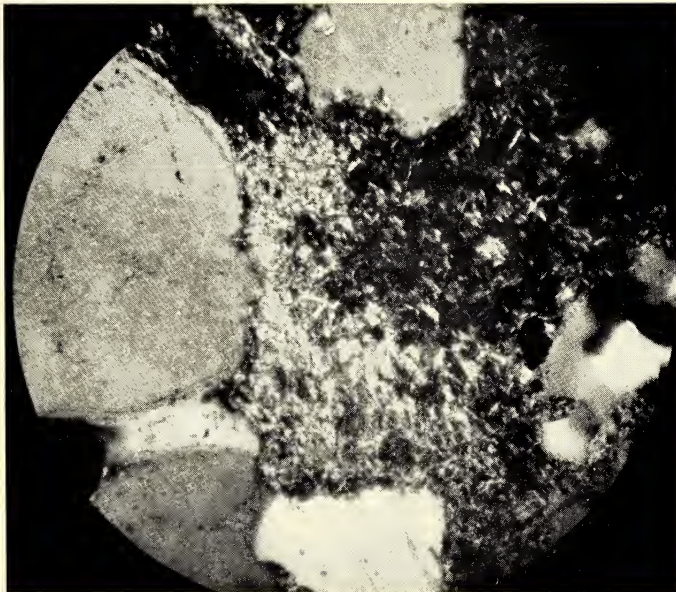
Fig. 2.

due to the loss of adsorbed moisture which is characteristic of the illites. This is followed by a small and variable exothermic peak in the region of 300–400° C. The relatively large endothermic peak between 550 and 600 degrees is due to the loss of lattice water from both illite and kaolinite. The loss for kaolinite is rather sharp but with illite it is somewhat broad and variable. Consequently with natural mixtures of these minerals the peaks are variable in both shape and position. The final breakdown of the mixtures is represented by the very small exothermic peak in the region of 1000° C.

TABLE 1.

X-Ray Data.

1		2		3		4		5		6	
d	I	d	I	d	I	d	I	d	I	d	I
9·82	8	9·78	10	9·78	9	9·94	9	9·78	9	9·78	9
7·15	1			7·05	8			7·10	5	7·20	6
4·98	1	4·94	2	4·89	2	4·98	2	4·96	4	4·95	2
4·46	4	4·47	8	4·40	5	4·43	7	4·45	3	4·47	10
				4·12	5						
3·62	4	3·64	5	3·62	2	3·64	2			3·63	8
				3·56	8			3·55	6	3·56	5
3·35	10	3·34	10	3·35	8	3·32	10	3·34	10	3·35	10
3·06	3	3·05	5	3·04	3	3·04	4	3·07	2	3·06	6
				2·68	2	2·66	1	2·70	4	2·68	2
2·56	10	2·56	10	2·55	10	2·56	8	2·50	7	2·55	10
		2·43	2								
		2·38	2								
2·01	4	2·00	8	2·00	9	2·00	4	2·00	5	2·00	4
1·50	7	1·50	10	1·50	9	1·50	6	1·50	6	1·50	9

X-ray data for the six samples are given in Table 1. The analyses were carried out on materials previously treated with glycerol to enable the detection of possible mixed layering. All samples show a predominance of illite, whilst samples 1, 3, 5 and 6 contain kaolinite in subordinate amounts. The estimated compositions are given in Table 2.

TABLE 2.

Composition of Samples Estimated from X-Ray Data.

Mineral.	1	2	3	4	5	6
Illite (%)	90	100	60	100	75	70
Kaolinite (%) ..	10	—	40	—	25	30

DISCUSSION.

Millot (1952), Grim (1953) and others have shown that kaolinite is the predominant mineral in fresh water sediments, while illite is relatively rare. The examination by one of the authors (F.C.L.) of numerous samples of shales occurring as lenses in the Hawkesbury Sandstone appears to verify this conclusion; consequently the prevalence of illite in the matrices of the sandstones examined suggests an authigenic rather than an allogenic origin. Thin section studies of the sandstones revealed low birefringent cores, apparently of

kaolinite, surrounded by illite (Plate III, Fig. 1) and corroded margins of some quartz grains appear to have reacted with clay minerals to form illite (Plate I, Fig. 2).

The formation of illite from kaolinite involves the addition of potash and either the addition of silica or the depletion of alumina. The prevalence of secondary enlargement of quartz grains (Plate III, Fig. 2) attests to the availability of soluble silica, thus favouring the former possibility. Further, since the conversion of kaolinite to illite by the addition of silica involves a volume increase of approximately 40%, the high proportion of matrix in otherwise typical quartzose sandstones is partially accounted for.

The source of the potash is more speculative. According to Pask and Davies (1945) the potash content of illite varies from $6 \cdot 2\%$ to $9 \cdot 1\%$, depending on the extent of replacement (alumina for silica) in the tetrahedral layers. Hence 2% to 3% of available potash is required.

Since the deposits are of fresh water origin, connate water as a source of the potash appears unlikely. Moreover, in the absence of associated salt deposits, translocation of potash by circulating groundwater seems also unlikely.

The breakdown of detrital grains of potash-bearing minerals is a further possibility. Thus an original content of 10% to 15% of potash-bearing felspars would provide the necessary potash. Felspar is relatively rare in the samples examined, the amounts seen in thin section ranging from almost nil to about 1%. Since some felspar grains show corroded margins at clay contacts, however, the former presence of greater amounts of felspars is suggested.

It is concluded that the illite occurring in the matrices of the sandstones examined is authigenic in origin and has been derived from allogenic kaolinite by the interaction of that mineral with silicic and potassic waters, the potash possibly being derived from the breakdown of detrital felspar.

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EXPLANATION OF PLATE III.

Fig. 1.—Portion of interstitial clay matrix in Hawkesbury Sandstone from Maroubra Quarry, Sydney. Crossed polars. ×100. Illite surrounding core of low birefringent clay.

Fig. 2.—As last. Some quartz grains show thin secondary rims, others show corroded margins apparently resulting from reaction of quartz and clay to form illite.

REFRACTION IN PHOTOGRAPHIC ASTROMETRY.

By Harley Wood.

ABSTRACT.

A new derivation is given of the formulæ for calculating the effect of refraction on the positions of stars on a photographic plate together with a discussion on when the various terms need to be applied.

The effect of refraction on the position of a star on a photographic plate which has its centre at the zenith is easily calculated. If the plate is centred elsewhere in the sky we may seek to carry out the transformation which gives the position of the star on a plate with centre at the zenith. The corrections for refraction may then be calculated and the transformation applied to refer the star's position back to the original centre, as freed from the effect of refraction. Here it will be shown how these transformations may be carried out to derive the formulæ for differential refraction by representing the star places as vectors.

Let x', y' be the measured coordinates of a star on a celestial photograph including the effects of refraction but not other errors. The y' axis is taken as directed northward along the hour circle as affected by refraction. Let us regard the plate as tangential to the (unit) sphere and take the coordinates λ', μ', ν' for the star from the centre of the sphere where the λ', μ' axes are parallel to the x', y' axes and ν' is perpendicular to these, that is the line from the centre of the sphere to the centre of the plate. Then the vector V' of the position of the star from the centre of the sphere is $\lambda' = x'$, $\mu' = y'$, $\nu' = 1$.

Let η be the apparent parallactic angle at the centre of the plate, z_c the zenith distance, affected by refraction, of the centre of the plate, and z the zenith distance of a star which appears on the plate.

Transform the vector V' firstly by a rotation about the ν' axis so that the new μ axis would be directed towards the zenith and then by a rotation z_c about the λ axis as placed after the first rotation so that the ν axis then passes through the zenith. The vector, V' for the star on the plate is, in the new coordinate system, now $V'' = \lambda''$, μ'', ν'' and the coordinates the star would have on a plate centred at the zenith are

$$x'' = \lambda''/\nu'' \text{ and } y'' = \mu''/\nu'', \quad \dots\dots\dots\dots (1)$$

where the old plate centre is on the y'' axis in the negative direction.

The coordinate transformation outlined above is given by

$$V'' = \begin{bmatrix} \cos \eta & -\sin \eta & 0 \\ \sin \eta \cos z_c & \cos \eta \cos z_c & -\sin z_c \\ \sin \eta \sin z_c & \cos \eta \sin z_c & \cos z_c \end{bmatrix} V' \quad \dots\dots (2)$$

The coordinates x'', y'' can now be freed conveniently of the effects of refraction.

Let ζ be the zenith distance of the star with the refraction removed. Then

$$\tan^2 z = x''^2 + y''^2 \quad \dots\dots\dots\dots\dots\dots (3)$$

and

$$\zeta = z + R_z \tan z, \quad \dots\dots\dots\dots\dots (4)$$

with

$$R_z = R_0 + R_1 \tan^2 z. \quad \dots\dots\dots\dots\dots (5)$$

So

$$\tan \zeta = \tan z + R_z \tan z \sec^2 z$$
$$= \tan z \,(1 + R_z \sec^2 z) \quad \dots\dots\dots\dots (6)$$

in which only terms to the first order in R_z have been retained.

The coordinates x''', y''' of the star on the plate centred at the zenith after removing refraction are given by

$$x''' = x'' \tan \zeta / \tan z$$
$$= x'' \,(1 + R_z \sec^2 z)$$
$$= x''\{1 + R_z(1 + x''^2 + y''^2)\}, \quad \dots\dots\dots\dots (7)$$

where use has been made of (3), and

$$y''' = y''\{1 + R_z(1 + x''^2 + y''^2)\}. \quad \dots\dots\dots\dots (8)$$

From (1) we have

$$1 + x''^2 + y''^2 = (\lambda''^2 + \mu''^2 + \nu''^2)/\nu''^2. \quad \dots\dots\dots\dots (9)$$

Since V' and V'' are representations of the same vector

$$\lambda''^2 + \mu''^2 + \nu''^2 = 1 + x'^2 + y'^2. \quad \dots\dots\dots\dots\dots (10)$$

also from (2) we have

$$\nu'' = x' \sin \eta \sin z_c + y' \cos \eta \sin z_c + \cos z_c$$
$$= \cos z_c(1 + Xx' + Yy'), \quad \dots\dots\dots\dots (11)$$

where we have written

$$\sin \eta \tan z_c = X \quad \text{and} \quad \cos \eta \tan z_c = Y. \quad \dots\dots\dots\dots (12)$$

and so

$$\sec^2 z = \frac{1 + x'^2 + y'^2}{(1 + Xx' + Yy')^2} \sec^2 z_c. \quad \dots\dots\dots\dots (13)$$

If we place

$$G = R_z \frac{1 + x'^2 + y'^2}{(1 + Xx' + Yy')^2}$$

equations (7) and (8) take the form

$$x''' = x''(1 + G \sec^2 z_c)$$
$$y''' = y''(1 + G \sec^2 z_c).$$

From this it is seen that the vector V''' (λ''', μ''', ν''') represents the direction of the star freed from the effects of refraction if

$$V''' = \begin{bmatrix} 1 + G \sec^2 z_c & 0 & 0 \\ 0 & 1 + G \sec^2 z_c & 0 \\ 0 & 0 & 1 \end{bmatrix} V'' \quad \dots\dots (14)$$

The transformation which refers the position of the star to the original plate centre may now be made. If the equatorial coordinates of the plate centre have been found by interpolating for its position among stars whose coordinates on the plate have been measured then the plate centre will have been subjected

to refraction along with the stars. The required transformation is therefore the inverse of (2) except that z_c is replaced by $z_c + R_c \tan z_c$ where $R_c = R_0 + R_1 \tan^2 z_c$.

That is, the vector V (λ, μ, ν) giving the position of the star is

$$V = \begin{bmatrix} \cos \eta & \sin \eta \cos (z_c + R_c \tan z_c) & \sin \eta \sin (z_c + R_c \tan z_c) \\ -\sin \eta & \cos \eta \cos (z_c + R_c \tan z_c) & \cos \eta \sin (z_c + R_c \tan z_c) \\ 0 & -\sin (z_c + R_c \tan z_c) & \cos (z_c + R_c \tan z_c) \end{bmatrix} V'''$$

$$\dots \dots \dots \dots \dots \dots (15)$$

If the transformations (2), (14) and (15) are combined by multiplying the matrices, making the substitutions (12) wherever appropriate and using

$$\sin (z_c + R_c \tan z_c) = \sin z_c + R_c \tan z_c \cos z_c$$

and
$$\cos (z_c + R_c \tan z_c) = \cos z_c - R_c \tan z_c \sin z_c,$$

we obtain

$$V = \begin{bmatrix} 1 + G + GY^2 & -GXY & -GX + R_c X \\ -GXY & 1 + G + GX^2 & -GY + R_c Y \\ -GX - R_c X & -GY - R_c Y & 1 + GX^2 + GY^2 \end{bmatrix} V' \quad \dots (16)$$

The formulæ for the coordinates on the plate with the effects of refraction removed are thus

$$\begin{aligned} x &= \lambda/\nu \\ &= x' + R_c(X + Xx'^2 + Yx'y') \\ &\quad - G(X - x' + X^2x' + XYy' - Xx'^2 - Yx'y') \quad \dots \dots \dots \dots (17) \end{aligned}$$

and

$$\begin{aligned} y &= y' + R_c(Y + Yy'^2 + Xx'y') \\ &\quad - G(Y - y' + Y^2y' + XYx' - Yy'^2 - Xx'y') \quad \dots \dots \dots \dots (18) \end{aligned}$$

where terms in G^2, R_c^2 and GR_c are omitted.

In order to develop the formulæ (17) and (18) R_c and R_z are replaced according to the expression (5) by

$$\begin{aligned} R_c &= R_0 + R_1 \tan^2 z_c \\ &= R_0 + R_1(X^2 + Y^2), \\ R_z &= R_0 + R_1 \tan^2 z \end{aligned}$$

$$= R_0 + R_1 \left\{ \frac{1 + x'^2 + y'^2}{(1 + Xx' + Yy')^2}(1 + X^2 + Y^2) - 1 \right\},$$

where use has been made of (13) and (12).

Hence

$$G = \left[R_0 + R_1 \left\{ \frac{1 + x'^2 + y'^2}{(1 + Xx' + Yy')^2}(1 + X^2 + Y^2) - 1 \right\} \right] \frac{1 + x'^2 + y'^2}{(1 + Xx' + Yy')^2}$$

$$\begin{aligned} = R_0 \{ &1 - 2Xx' - 2Yy' + x'^2(1 + 3X^2) + 6XYx'y' + y'^2(1 + 3Y^2) \\ &- 4(Xx' + Yy')^3 - (x'^2 + y'^2)(2Xx' + 2Yy') \dots \} \\ + R_1 \{ &X^2 + Y^2 - x'(2X + 4XY^2 + 4X^3) - y'(2Y + 4X^2Y + 4Y^3) \\ &+ x'^2(1 + 9X^2 + 2Y^2 + 10X^2Y^2 + 10X^4) + x'y'(14XY + 20XY^3 \\ &+ 20X^3Y) + y'^2(1 + 2X^2 + 9Y^2 + 10X^2Y^2 + 10Y^4) \dots \} \end{aligned}$$

By inserting the values of R_c and G in (17) and (18) we obtain

$$\begin{aligned}
x = {} & x' + R_0(1+X^2)x' + R_0 XYy' \\
& - R_0\{(X+X^3)x'^2 + 2X^2Yx'y' + (X+XY^2)y'^2\} \\
& + R_0\{(1+2X^2+X^4)x'^3 + (3XY+3X^3Y)x'^2y' + (1+X^2+Y^2+3X^2Y^2)x'y'^2 \\
& + (XY+XY^3)y'^3\} \\
& + R_1\{(3X^2+Y^2+3X^4+3X^2Y^2)x' + (2XY+3X^3Y+3XY^3)y'\} \\
& - R_1\{(3X+9X^3+4XY^2+6X^5+6X^3Y^2)x'^2 \\
& \quad + (2Y+12X^2Y+2Y^3+12X^4Y+12X^2Y^3)x'y' \\
& \quad + (X+2X^3+7XY^2+6X^3Y^2+6XY^4)y'^2\}
\end{aligned}$$

$$\cdots\cdots\cdots \quad (19)$$

and

$$\begin{aligned}
y = {} & y' + R_0(1+Y^2)y' + R_0 XYx' \\
& - R_0\{(Y+X^2Y)x'^2 + 2XY^2x'y' + (Y+Y^3)y'^2\} \\
& + R_0\{(XY+X^3Y)x'^3 + (1+X^2+Y^2+3X^2Y^2)x'^2y' + (3XY+3XY^3)x'y'^2 \\
& + (1+2Y^2+Y^4)y'^3\} \\
& + R_1\{(2XY+3X^3Y+3XY^3)x' + (X^2+3Y^2+3X^2Y^2+3Y^4)y'\} \\
& - R_1\{(Y+7X^2Y+2Y^3+6X^4Y+6X^2Y^3)x'^2 \\
& \quad + (2X+2X^3+12XY^2+12X^3Y^2+12XY^4)x'y' \\
& \quad + (3Y+4X^2Y+9Y^3+6X^2Y^3+6Y^5)y'^2\}
\end{aligned}$$

$$\cdots\cdots\cdots \quad (20)$$

If in working on formulæ (17) and (18) we retain R_c, write

$$R_z = R_c + R_1(\tan^2 z - \tan^2 z_c)$$

and develop G and hence x and y as before or if we substitute

$$\begin{aligned}
R_0 &= R_c - R_1\tan^2 z_c \\
&= R_c - R_1(X^2+Y^2)
\end{aligned}$$

in (19) and (20) we derive the exactly equivalent formulæ of Kapteyn as given in corrected form by Vick (1934).

If instead of (15) we apply the inverse of (2), thus omitting $R_c \tan z_c$ from (15) and referring the position of the star with the effect of refraction removed to the original plate centre, still affected by refraction, we obtain

$$V = \begin{bmatrix} 1+G+GY^2 & -GXY & -GX \\ -GXY & 1+G+GX^2 & -GY \\ -GX & -GY & 1+GX^2+GY^2 \end{bmatrix} V$$

This if developed in the same way as before to the stage reached in formulæ (19) and (20) gives the formulæ of Turner (1897).

In applying these formulæ the second and high order terms in x', y' may be calculated and applied as corrections to the measured coordinates of each object on the plate, while the lower orders are allowed for in the plate constants. If, as is usual, the right ascension and declination of the centre to be used in the computation of the standard coordinates of the reference stars are found by interpolating between the mean places of some nearby stars then the Kapteyn formula, (19) and (20), is the correct one to use. This regards as plate centre

for the purpose of calculation the point in the heavens which is represented at the place on the plate where the perpendicular from the second nodal point of the lens falls.

The derivation shows clearly the relation between the two formulæ. Turner's formula may be applied to give a correct result. It takes the plate centre to be the point of the celestial sphere towards which the telescope was directed at the time of the exposure, the atmosphere being regarded as absent. In finding the centre for the calculation of standard coordinates in applying Turner's formula the refraction in right ascension and declination must be added to the mean places of the stars being used before the interpolation is done. The second (and higher) order terms may then be applied to the measured coordinates of all the stars on the plate and the plate constants calculated as usual.

The value of R_0, agreeing with sufficient accuracy with the Pulkovo refraction tables, is given in seconds of arc following Comstock (1895) by

$$R_0 = \frac{21 \cdot 5b}{271 + t}$$

where b is the barometric pressure in millimetres of mercury corrected, if need be, for latitude to 60° and for the temperature of the mercury column, and t is the temperature in degrees centigrade. $R_1 = -0° \cdot 067$. Often it will be possible to use a mean value of R_0 appropriate to the observatory but if an error of $0 \cdot 05$ of the value of the second order terms is undesirable in the computations it is necessary to take account of the meteorological factors.

In order to estimate the zenith distances at which the various terms of formulæ (19) and (20) become appreciable they can be simplified by supposing the plate to be centred on the meridian, in which case $X=0$ and $Y=\tan z_c$. Consider the effects along the circumference of a circle of radius r with centre at the centre of the plate $(x'^2 + y'^2 = r^2)$.

Then the formulæ for differential refraction become

$$\begin{aligned}
x &= x'(1 + R_0) + R_0 x'(r^2 + y'^2 Y^2) \\
&\quad + R_1 Y^2 x' - R_1 (2Y + 2Y^3) x'y' \\
y &= y'(1 + R_0 + R_0 Y^2) - R_0 (r^2 Y + y'^2 Y^3) \\
&\quad + R_0 y'\{r^2(1 + Y^2) + y'^2(Y^2 + Y^4)\} \\
&\quad + R_1 y'(3Y^2 + 3Y^4) \\
&\quad - R_1\{r^2(Y + 2Y^3) + y'^2(2Y + 7Y^3 + 6Y^5)\}.
\end{aligned}$$

The coefficients of R_0 and R_1 of each order in the coordinates on the plate can have a larger value in the expression for y than in that for x and in each case these are greatest when $x'=0$, $y'=r$. That is, as might be expected, the greatest effect of refraction occurs on the vertical through the plate centre. In this case

$$\begin{aligned}
y &= r(1 + R_0 + R_0 Y^2) \\
&\quad - R_0 r^2 (Y + Y^3) \\
&\quad + R_0 r^3 (1 + 2Y^2 + Y^4) \\
&\quad + R_1 r(3Y^2 + 3Y^4) \\
&\quad - R_1 r^2 (3Y + 9Y^3 + 6Y^5).
\end{aligned}$$

The radius of the field at which the terms attain $1''$, $0'' \cdot 04$ and $0'' \cdot 001$ is given for various zenith distances in Table 1, which is calculated with $R_0 = 58''$ and $R_1 = -0'' \cdot 067$.

These errors correspond roughly to three categories into which positional observations may be divided. Firstly there are observations, such as those on comets, or minor planets, in which second order terms in refraction would not usually be applied. Secondly may be considered observations in which the probable error of the position may be expected to be about $0''\cdot12$ and in which the second order terms must be calculated if they reach about a quarter of this. Observations for star catalogues or precise observations of minor planets selected for the determination of astronomical constants are of this kind. Thirdly there is the type of observation where the effect of refraction can be strictly systematic in its effect on a final result of high precision as in the observation of

TABLE 1.

z_c	R_0 Second order terms attain			R_0 Third order terms attain			R_1 Second order terms attain		
	$1''$	$0''\cdot04$	$0''\cdot001$	$1''$	$0''\cdot04$	$0''\cdot001$	$1''$	$0''\cdot04$	$0''\cdot001$
	for field of radius			for field of radius			for field of radius		
°	°	°	°	°	°	°			
20	11·7	2·3	0·37	13·6	4·6	1·4			
28	9·1	1·8	0·29	12·4	4·2	1·2			
36	7·2	1·4	0·23	11·2	3·8	1·1	°	°	°
44	5·5	1·2	0·17	9·6	3·3	1·0	55·3	11·1	1·7
52	4·1	0·8	0·13	7·7	2·6	0·8	33·6	6·7	1·1
60	2·9	0·6	0·09	5·8	2·0	0·6	18·3	3·7	0·6
68	1·8	0·4	0·06	4·0	1·4	0·4	8·4	1·7	0·3
76	0·9	0·2	0·03	2·2	0·8	0·2	2·7	0·5	0·1

Eros for the determination of its parallax. In this connection Sir H. Spencer-Jones (1931), in referring to some possible systematic errors amounting to $0''\cdot0016$ or $0''\cdot0009$, pointed out that " these errors are not negligible compared with the probable errors to be expected from the programme ". If observations in this third category are made at zenith distances approaching 60° it is evident that the third order coefficients of R_0 and the second order of R_1 should be considered if the reference stars extend to more than half a degree from the plate centre. Usually the programme of observations for stellar parallax, which also come within the third category of accuracy, will be arranged so that the effects of refraction, being almost the same on the various plates, can be eliminated from consideration as a systematic effect.

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A NOTE ON A GENERALISATION OF WEBER'S TRANSFORM.

By James L. Griffith.

School of Mathematics, New South Wales University of Technology.

In this note, we indicate a generalisation of the Weber transform which was given in Titchmarsh (1946), §4.10. If we assume that $J_\nu(t)$ and $Y_\nu(t)$ are the Bessel functions of the first and second kind of order ν, and write

$$C_\nu(z, w) \equiv J_\nu(z)[PY_\nu(w) - QwY_{\nu+1}(w)] - Y_\nu(z)[PJ_\nu(w) - QwJ_{\nu+1}(w)] \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where P and Q are arbitrary constants, the transform we will consider will be

$$F(s) = \int_a^\infty x C_\nu(xs, as) f(x) dx \qquad \cdots\cdots\cdots\cdots\cdots (2)$$

Since Titchmarsh treats the case when $Q=0$, we will assume that $Q \neq 0$.

The interesting point of this transform is that there are three different forms of the inversion theorem. These forms depend on the values of the parameter P/Q.

The derivation of these formulae will be almost entirely formal, and to simplify the work the notation of Titchmarsh (1946) will be used.

The solutions $\varphi(x, \lambda)$ and $\theta(x, \lambda)$ of

$$\frac{d^2y}{dx^2} + \left(s^2 - \frac{\nu^2 - \frac{1}{4}}{x^2}\right)y = 0, \quad \lambda = s^2, \qquad \cdots\cdots\cdots\cdots (3)$$

which satisfy the boundary conditions

$$\varphi(a, \lambda) = \sin \alpha, \quad \varphi'(a, \lambda) = -\cos \alpha, \qquad \cdots\cdots\cdots\cdots\cdots (4a)$$

and

$$\theta(a, \lambda) = \cos \alpha, \quad \theta'(a, \lambda) = \sin \alpha, \qquad \cdots\cdots\cdots\cdots (4b)$$

are

$$\varphi(x, \lambda) = x^{\frac{1}{2}}[AJ_\nu(xs) + BY_\nu(xs)] \qquad \cdots\cdots\cdots\cdots (5a)$$

and

$$\theta(x, \lambda) = x^{\frac{1}{2}}[CJ_\nu(xs) + DY_\nu(xs)]. \qquad \cdots\cdots\cdots\cdots (5b)$$

The constants in equations (5a) and (5b) are given by

$$A \equiv A(\alpha, Y) = \tfrac{1}{2}\pi Y_\nu(as)[a^{\frac{1}{2}} \cos \alpha + (\tfrac{1}{2} + \nu)a^{-\frac{1}{2}} \sin \alpha] - \tfrac{1}{2}\pi Y_{\nu+1}(as)[a^{\frac{1}{2}}s \sin \alpha]$$
$$B = -A(\alpha, J); \quad C = A(\alpha + \tfrac{1}{2}\pi, Y); \quad D = -A(\alpha + \tfrac{1}{2}\pi, J) \qquad \cdots\cdots\cdots (6)$$

L

Now $m(\lambda)$ which is determined so as to obtain a solution of (3) of the form $\theta(x, \lambda) + m(\lambda)\varphi(x, \lambda)$, which is small for $\mathrm{Im}\,[m(\lambda)] \to \infty$, is found to be

$$m(\lambda) = \frac{[-a^{\frac{1}{2}}\sin\,\alpha + (\nu+\tfrac{1}{2})a^{-\frac{1}{2}}\cos\,\alpha]H_\nu^{(1)}(as) - a^{\frac{1}{2}}s\cos\,\alpha\,H_{\nu+1}^{(1)}(as)}{[a^{\frac{1}{2}}\cos\,\alpha + (\nu+\tfrac{1}{2})a^{-\frac{1}{2}}\sin\,\alpha]H_\nu^{(1)}(as) - a^{\frac{1}{2}}s\sin\,\alpha\,H_{\nu+1}^{(1)}(as)} \quad .. \quad (7)$$

We now put

$$P = \tfrac{1}{2}\pi[a^{\frac{1}{2}}\cos\,\alpha + (\nu+\tfrac{1}{2})a^{-\frac{1}{2}}\sin\,\alpha] \quad \ldots\ldots\ldots\ldots \quad (8a)$$

and

$$Q = \tfrac{1}{2}\pi a^{-\frac{1}{2}}\sin\,\alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8b)$$

whence

$$\varphi(x, \lambda) = x^{\frac{1}{2}}C_\nu(xs,\,as)$$

and

$$m(\lambda) = \cot\,\alpha + \frac{\pi^2 H_\nu^{(1)}(as)}{4Q\hbar_\nu^{(1)}(as)}$$

where

$$\hbar_\nu^{(1)}(z) \equiv PH_\nu^{(1)}(z) - QzH_{\nu+1}^{(1)}(z). \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Now, in a paper to be published elsewhere, I have proved that

(i) $\hbar_\nu^{(1)}(z)$ has no zeros above the real axis, when $2\nu - P/Q \geq 0$;

(ii) $\hbar_\nu^{(1)}(z)$ has one zero and only one above the real axis, when $2\nu - P/Q < 0$ (this zero is a simple zero on the imaginary axis) ;

(iii) when $2\nu - P/Q = 0$ and $0 < \nu < 2$, $z = 0$ is a zero of $\hbar_\nu^{(1)}(z)$;

(iv) except as stated in (iii), there are no zeros of $\hbar_\nu^{(1)}(z)$ on the real axis.

When $\lambda < 0$, the well-known formula $H_\nu^{(1)}(z) = 2\pi e^{-\frac{1}{2}(\nu+1)\pi i}K_\nu(z)$ shows that $m(\lambda)$ is real. When $\lambda > 0$,

$$-\mathrm{Im}\,[m(\lambda)] = \frac{\tfrac{1}{2}\pi}{|\,\hbar_\nu^{(1)}(as)\,|}$$

When $2\nu - P/Q > 0$, there is no pole of $\hbar_\nu^{(1)}(as)$ on the real axis. However, if $2\nu - P/Q < 0$, there is a pole on the negative real axis (at $\lambda = -\lambda_0$, $s = s_0 = -i\sigma_0$ (say)). We calculate the residue at $\lambda = -\lambda_0$ and find that it is

$$-\frac{\tfrac{1}{2}\pi^2 s_0^2}{P(P-2Q\nu) + Q^2a^2s_0^2}$$

When we consider the case $2\nu - P/Q = 0$, we observe that both the numerator and denominator of $m(\lambda)$ have singularities at the origin. From the asymptotic expansions in the neighbourhood of the origin, it will be seen that $m(\lambda)$ will have a pole at the origin with residue $\tfrac{1}{2}\pi^2(\nu-1)a^{-2}Q^{-2}$ when $\nu > 1$, but will not have a pole otherwise.

Thus $k(\lambda) = -\lim\limits_{\delta\to 0+}\int_{-\infty}^{\lambda}\mathrm{Im}\,[m(u+i\delta)]du$ will be given by :

(i) $2\nu - P/Q > 0$ or $2\nu - P/Q = 0$, $0 \leq \nu \leq 1$,

$$k(\lambda) = \begin{cases} 0, & \lambda < 0 \\ \int_0^\lambda \tfrac{1}{2}\pi\,|\,\hbar_\nu^{(1)}(as)\,|^{-2}d\lambda, & \lambda \geq 0 \end{cases}$$

(ii) $2\nu - P/Q < 0$,

$$k(\lambda) = \begin{cases} 0, & \lambda < -\lambda_0 \\[2mm] -\dfrac{\frac{1}{2}\pi^3 s_0^2}{P(P-2Q\nu)+Q^2a^2s_0^2}, & -\lambda_0 < \lambda < 0 \\[4mm] -\dfrac{\frac{1}{2}\pi^3 s_0^2}{P(P-2Q\nu)+Q^2a^2s_0^2} + \displaystyle\int_0^\lambda \tfrac{1}{2}\pi \mid \hbar_\nu^{(1)}(as) \mid^{-2} d\lambda, & \lambda \geq 0 \end{cases}$$

(iii) $2\nu - P/Q = 0$, $\nu > 1$,

$$k(\lambda) = \begin{cases} 0, & \lambda < 0 \\[2mm] \tfrac{1}{2}\pi^3(\nu-1)a^{-2}Q^{-2} + \displaystyle\int_0^\lambda \tfrac{1}{2}\pi \mid \hbar_\nu^{(1)}(as) \mid^{-2} d\lambda, & \lambda \geq 0. \end{cases}$$

We now use the formulae (3.1.2) and (3.1.3) of Titchmarsh (1946) and replace $f(x)$ of these formulae by $x^{\frac{1}{2}}f(x)$ and obtain the transform

$$F(s) = \int_a^\infty x C_\nu(xs, as) f(x) dx$$

and its inversion formulae

(i) $2\nu - P/Q > 0$ or $2\nu - P/Q = 0$, $0 \leq \nu \leq 1$,

$$f(x) = \int_0^\infty \frac{s C_\nu(xs, as)}{\mid \hbar_\nu^{(1)}(as) \mid^2} F(s) ds; \qquad \dots\dots\dots\dots\dots\dots\dots \quad (10a)$$

(ii) $2\nu - P/Q < 0$,

$$f(x) = -\frac{Q\pi s_0^2 H_\nu^{(1)}(xs_0) F(s_0)}{[P(P-2Q\nu)+Q^2a^2s_0^2]H_\nu^{(1)}(as_0)} + \int_0^\infty \frac{x C_\nu(xs, as)}{\mid \hbar_\nu^{(1)}(as) \mid^2} F(s) ds$$
$$\dots\dots\dots\dots\dots\dots\dots\dots \quad (10b)$$

(iii) $2\nu - P/Q = 0$, $\nu > 1$

$$f(x) = \frac{\pi(\nu-1)x^{-\nu}F(0)}{Qa^{2-\nu}} + \int_0^\infty \frac{x C_\nu(xs, as)}{\mid \hbar_\nu^{(1)}(as) \mid^2} F(s) ds. \qquad \dots\dots\dots\dots \quad (10c)$$

In constructing the first term on the right side of equation (10b) we have noted that

$$C_\nu(xs_0, as_0) = \frac{2Q H_\nu^{(1)}(xs_0)}{\pi H_\nu^{(1)}(as_0)}$$

while in the first term on the right side of equation (10c) after examining the asymptotic formulae for the Bessel functions we have defined

$$C_\nu(xs, as)_{s=0} = 2Qa^\nu \pi^{-1} x^{-\nu}$$

As Parseval formulae for the product of two transforms $F(s) = T[f(x)]$ and $G(s) = T[g(x)]$ we obtain

(i) $2\nu - P/Q > 0$ or $2\nu - P/Q = 0$, $0 \leq \nu \leq 1$,

$$\int_a^\infty x f(x) g(x) dx = \int_0^\infty \frac{s F(s) G(s)}{\mid \hbar_\nu^{(1)}(as) \mid^2} ds; \qquad \dots\dots\dots\dots\dots \quad (11a)$$

(ii) $2\nu - P/Q < 0$,

$$\int_a^\infty xf(x)g(x)dx = -\frac{\pi^2 s_0^2 F(s_0)G(s_0)}{P(P - 2Q\nu) + Q^2 a^2 s_0^2} + \int_0^\infty \frac{sF(s)G(s)}{|\hbar_\nu^{(1)}(as)|^2} ds \; ;$$

.... (11b)

(iii) $2\nu - P/Q = 0$, $\quad \nu > 1$,

$$\int_a^\infty xf(x)g(x)dx = \frac{\frac{1}{2}(\nu - 1)\pi^2 F(0)G(0)}{Q^2 a^2} + \int_0^\infty \frac{sF(s)G(s)}{|\hbar_\nu^{(1)}(as)|^2} ds. \quad \dots(11c)$$

Now, in our development, we have restricted P and Q to a certain extent ; for example, reference to equation (8b) shows that $|Q| < \frac{1}{2}\pi a^{-\frac{1}{2}}$.

If we now replace P and Q in equation (1) by kP and kQ (where k is any constant) and examine the resultant changes in equations (2), (10) and (11) we will see that this restriction is unnecessary and P and Q may take any real value except that $Q \neq 0$.

Before proceeding to indicate an application of the transform, it must be noted that one of the many sufficient conditions for equations (10) and (11) to hold is that $x^{\frac{1}{2}}f(x)$ and $x^{\frac{1}{2}}g(x)$ should belong to both $L^1(a, \infty)$ and $L^2(a, \infty)$.

Consider the equations

$$\frac{\partial^2 z}{\partial t^2} = v^2 \left(\frac{\partial^2 z}{\partial r^2} + \frac{1}{r} \frac{\partial z}{\partial r} \right) \quad \dots\dots\dots\dots\dots \quad (12a)$$

$$\frac{\partial z}{\partial r} + hz = 0 \quad \text{when} \quad r = a \quad \dots\dots\dots\dots \quad (12b)$$

$$z = f(r), \; \frac{\partial z}{\partial t} = 0 \quad \text{when} \quad t = 0. \quad \dots\dots\dots\dots \quad (12c)$$

We give P, Q and ν the values h, 1 and 0 respectively in equations (1), (2) and (10) and thus modify the transform to

$$G(s) = \int_a^\infty rC_0(rs, as)g(r)dr. \quad \dots\dots\dots\dots \quad (13)$$

Then applying the transform to equations (12) and proceeding formally we obtain

$$\frac{\partial^2 Z}{\partial t^2} = -v^2 s^2 Z \quad \dots\dots\dots\dots\dots \quad (14a)$$

$$Z = F(s), \; \frac{\partial Z}{\partial t} = 0 \quad \text{when} \quad t = 0 \quad \dots\dots\dots\dots \quad (14b)$$

These equations then give

$$Z = F(s) \cos vst \quad \dots\dots\dots\dots\dots \quad (15)$$

Now if $h < 0$ we have case (i) of the transform, so

$$z(r, t) = \int_0^\infty \frac{sC_0(rs, as)}{|\hbar_0^{(1)}(as)|^2} F(s) \cos vst \, ds \quad \dots\dots\dots \quad (16a)$$

and if $h > 0$ we have case (ii) with solution

$$z(r,\,t) = \frac{\pi\sigma_0^2 K_0(r\sigma_0)F(i\sigma_0)\cosh v\sigma_0 t}{(h^2 - a^2\sigma_0^2)K_0(a\sigma_0)} + \int_0^\infty \frac{sC_0(rs,\,as)}{\mid \mathfrak{h}_0^{(1)}(as)\mid^2}F(s)\cos vst\, ds$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16b)$$

where σ_0 is the root of $hK_0(az) - azK_1(az) = 0$.

(We have again used the formula connecting the $H_\nu^{(1)}$-functions and the K_ν-functions.)

The difference of form of the results is expected from physical considerations. The equations (12) represent the displacement of infinite membrane with a circular hole, under an external force along the edge of the hole. The force is proportional to the displacement. Case (i) is that of an attractive force and case (ii) that of a repulsive force.

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APPENDIX.

Appended to this note is a graph showing the relation between σ_0, C and ν where

$$CK_\nu(\sigma_0) - \sigma_0 K_{\nu+1}(\sigma_\nu) = 0.$$
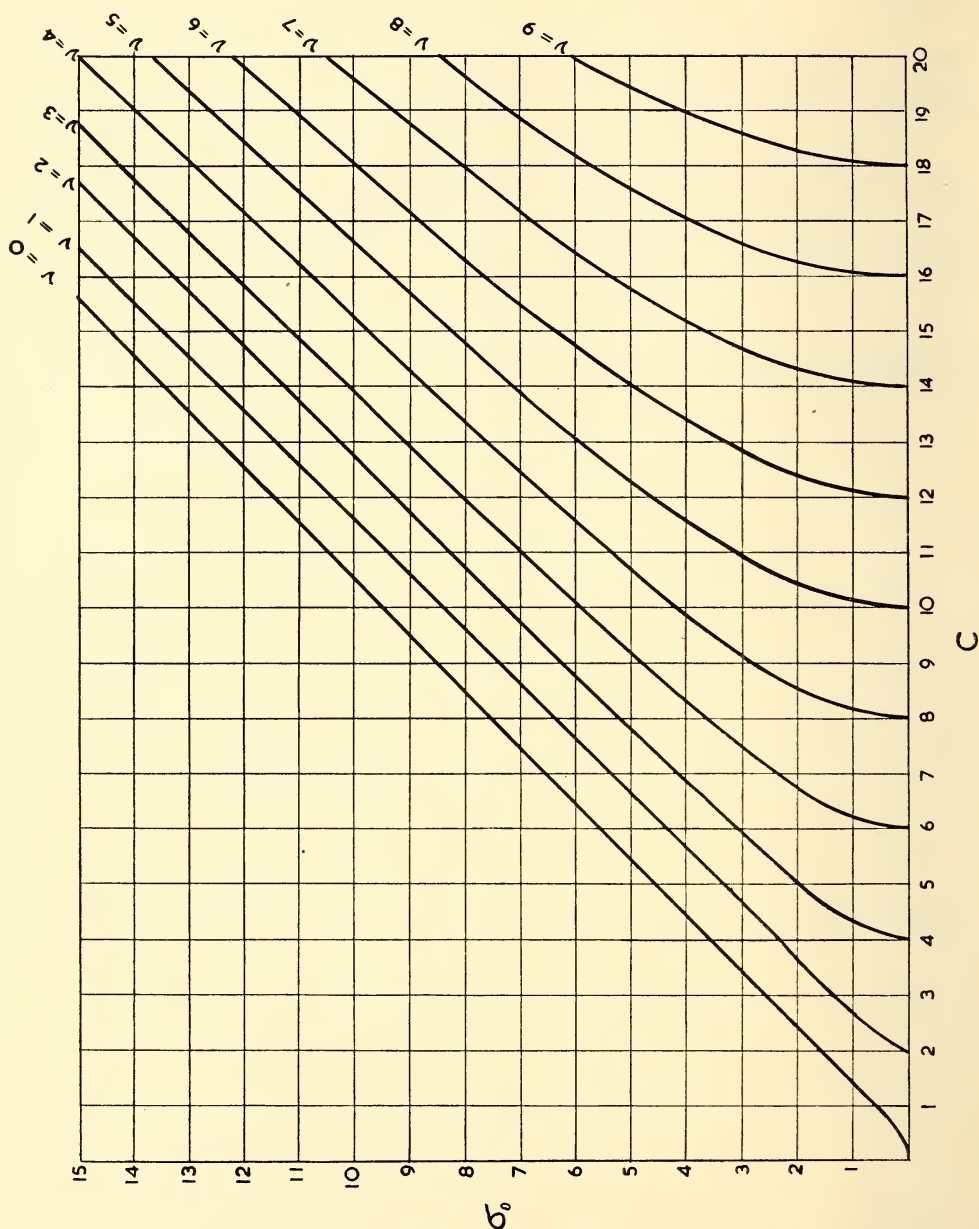
The curves have been calculated using the results in M.T X. Bessel Function, Part II, of the British Association for the Advancement of Science.

When C is large, the curves approximate to $C = \sigma_0 + (\nu + \frac{1}{2})$. However, the approximation is not rapid except for small values of ν. When $\nu = \frac{1}{2}$, the curve (not shown) is $C = \sigma_0 + 1$.

EFFICIENT USE OF A BOOSTER FAN IN MINE VENTILATION.

By M. H. McKay,

A. H. Low

and A. Keane.

School of Mathematics, New South Wales University of Technology.

Summary.

When leakage between the airways of a mine is such that the quantity of air reaching the working face is insufficient for the needs of men and machines, it is sometimes necessary to install an underground fan in the mine to supplement the main ventilating fan which is situated at the surface. The effect of such a booster fan on the ventilation of an " ideal " mine conforming to a certain type is discussed in this paper, and tables are presented to give the water gauge and position of the fan so that the quantity of air reaching the working face is a maximum for given values of the mine efficiency, defined as the ratio of the quantity of air reaching the working face to the quantity entering the mine.

1. Introduction.

§1.1. For solving problems connected with the ventilation of coal-mines, mining engineers have used Atkinson's formula, a relation connecting the pressure difference (P) between two points in a mine airway and the quantity of air (Q) flowing between the two points. The relation is usually written in the form

$$P = RQ^2, \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (1)$$

where units for P are lb./sq. ft., Q is in kilocusecs (1,000 cu. ft./sec.) and R, referred to as the " resistance " to airflow of that section of the airway between the two points, is in Atkinsons. An Atkinson is the resistance of a section of an airway through which 1 kilocusec of air flows due to a pressure difference of 1 lb./sq. ft. between the ends of the section, assuming that relation (1) holds.

Atkinson's formula (1) assumes that the quantity of air flowing is constant throughout the mine, thus taking no account of leakage. However, no matter which method of mining is used, it appears that the material between the airways of a mine actually approximates to uniform porosity. In the case of a settled goaf this is obviously so, and, where brick stoppings are put in to replace coal which has been removed between the headings, the fact that these stoppings are at relatively short intervals and the fact that cracks exist in the overburden combine to give approximately continuous porosity. Hence considerable leakage takes place from the intake to the return.

Storrow (1918) found experimentally that the flow of air through a brick was approximately streamlined, so that the relation between pressure drop across a brick and quantity of air passing through the pores of the brick may be taken as

$$P = RQ. \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

This relation has been accepted as appropriate for the flow through the porous barrier between the headings of a mine.

§1.2. In many considerations of mine ventilation it is assumed as a first approximation that leakage through the barrier between intake and return is too small to affect the flow in the airways to any appreciable extent. Thus the quantity flowing in the airways is taken to be constant, so that the pressure gradient is constant. However, in practice this is far from correct. Observation of a representative mine on the south coast of New South Wales reveals a loss in quantity in the main airways between the mine entrance and the working face of approximately 70%.

Peascod and Keane (1955) have built up a theory for the combined effects of flow in the airways and leakage through the porous barrier in a mine conforming to certain restrictive assumptions. In such a mine this theory may be used to predict, for any value of the fan water gauge, the results of a pressure survey (i.e. pressures and quantities throughout the mine) from the results of a pressure survey made at some given value of the fan water gauge. The type of mine to which the theory is applicable consists of two equal and parallel airways, an intake and a return, connected at the working face. They are of similar uniform construction, offering equal constant resistances to air flow per unit length, are only a small distance apart compared to their length, and are separated by a uniformly porous barrier. Such a mine will be referred to as an ideal mine.

In most mines the resistance to the airflow in the return is different from that in the intake. Low (1956) has shown that the results of Peascod and Keane hold good for such a mine if the resistance of intake and return are each taken as equal to the mean value of the two resistances.

§1.3. The theory of Peascod and Keane was built upon the assumption that Atkinson's formula (1) held for the relation between pressure drop and quantity of air flowing in the airways of a mine where no leakage occurs. However, for conditions prevailing in most mines, a more appropriate relation is that postulated by Reynolds and others (Lamb, 1953), viz.

$$P = RQ^n, \qquad \dotfill (3)$$

where n has some value slightly less than 2. It is obvious that the dimensions of R depend on the value of n, so that Atkinsons may not be used as units for the resistance when n is not equal to 2.

Groden (1956) has extended the theory of Peascod and Keane to cover this more general case, and has obtained tables giving the pressures and quantities throughout an ideal mine for $n = 1 \cdot 7$, $1 \cdot 8$ and $1 \cdot 9$ respectively. He has also given a method for determining the value of n when the pressure and quantity are given at three points of an ideal mine. The result obtained on applying this to the aforementioned representative mine was $n = 1 \cdot 75$, indicating that the earlier work of Peascod and Keane required some modification.

§1.4. When the quantity of air reaching the working face in a mine is insufficient for the needs of men and machines, it is sometimes necessary to install an underground fan in the mine. On the assumption that such a booster fan can be designed to fit the specifications, Keane and Peascod (1955, 1956) have extended the theory of leakage to determine the water gauge and position of a fan so that the quantity of air reaching the working face is a maximum for given values of the mine efficiency, defined as the ratio of the quantity of air reaching the working face to the quantity entering the mine. This work was also based on the assumption that the relation (1) held for flow in the airways. However, as seen earlier, this theory will not be satisfactory for all actual mines.

The present work was undertaken to extend the theory of the installation of an underground fan to the more general case where the relation (3) is taken

to hold.   Tables are presented for $n=1\cdot7$, $1\cdot8$ and $1\cdot9$ corresponding to those calculated by Keane and Peascod for $n=2$.

§1.5.   It should be noted that there is a possibility of recirculation in the vicinity of both the main fan and the underground fan due to leakage through the barrier from the high pressure side to the low pressure side of the fan.   This may be counteracted by airtight casing around the fans extending for a distance not less than the distance between the intake and return.   With this precaution only a small local effect would be in evidence and would make a negligible difference to leakage from intake to return over a distance of up to three miles.   As has been done previously, it will be assumed here that all leakage takes place from intake to return in a direction at right angles to the airways.

It will also be assumed in this paper that the density of air throughout the mine is constant.   It should be borne in mind that fans used to ventilate coal-mines cause a discontinuity in pressure of the order of 1/100 atmospheres and, consequently, the effect of compressibility is negligible.   Moreover, we have neglected the effect of oxidation occurring at the working face, which results in an increase in the temperature and the volume of the air on passing the face.

2. Specifications.

Following the notation used by Keane and Peascod we take r_1 as the assumed uniform resistance per unit length of the intake and return, which are taken to be equal and parallel, and r_2^{-1} as the assumed uniform " conductance " of the intervening porous barrier per unit length of airway.   We also assume that no pressure loss occurs at the working face connecting the intake and return.   We take L as the length of the intake and write $R_1=r_1L$ for the total resistance of the intake and $R_2=r_2L^{-1}$ as the total resistance of the porous barrier.

We take P_0 as the pressure difference due to the main fan, situated at the outlet of the return, and αP_0 $(0<\alpha<1)$ as the pressure difference due to the booster fan, situated in the return at a distance l_1 from the outlet and l_2 from the working face, so that $L=l_1+l_2$.   Since the air flow depends upon pressure differences throughout the mine and not upon outside atmospheric pressure we may assume zero pressure at the outlet of the return and take P_0 as the pressure at the entrance to the intake.

If P_1 is the pressure in the return immediately outbye of the booster fan, the pressure on the inbye side will be $P_1-\alpha P_0$ and the pressure at the point of the intake distant l_1 from the surface will be P_0-P_1, since, on the basis of our assumptions, the pressure drop along a length of the intake is the same as the pressure drop along the corresponding length of the return.   Hence, if the booster fan is so placed that the pressure difference between intake and return immediately outbye of the fan is zero, we have

$$P_0-P_1=P_1,$$

therefore $$P_1=\tfrac{1}{2}P_0. \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(4)}$$

We shall call this position of the fan the " neutral point ".   Such a position must exist since the pressure drops from P_0 at the entrance of the intake to $\tfrac{1}{2}P_0-\tfrac{1}{2}\alpha P_0$ at the working face, the total pressure drop in the airways being $P_0+\alpha P_0$.   If the fan is moved further inbye than the neutral point, the pressure in the intake becomes less than that on the immediate outbye side of the fan and so recirculation occurs, i.e. air will pass through the barrier from the return to the intake.

Peascod (1955) has shown that when leakage is small the quantity of air leaking through the barrier from intake to return decreases as the booster fan

is moved inbye from the outlet, so that, avoiding recirculation, the most effective position for the underground fan is at the neutral point. We assume that this also applies when leakage is considerable. For the case when the flow index, n, is taken equal to 2, it is possible to prove that this assumption is correct by expressing the mine variables in terms of elliptic functions (Keane, 1956), but this method of proof cannot be extended to the general case.

The booster fan is thus assumed to be at the neutral point of the return, so that pressures at various points of the airway may be taken as shown in Figure 1, where AA_1 is a typical transverse section of the mine on the outbye side of the fan and BB_1 a typical transverse section on the inbye side.
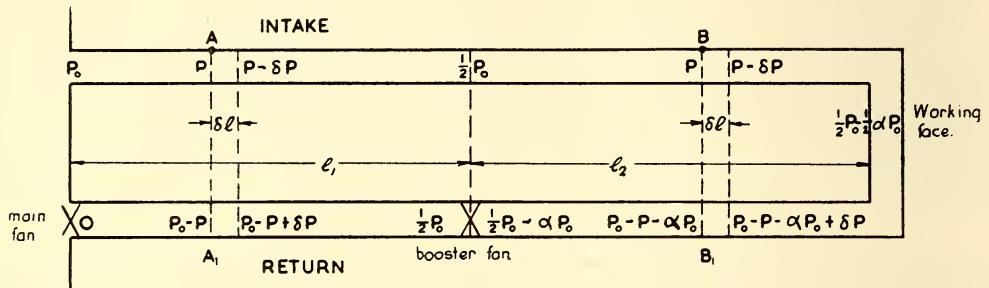
Fig I. - Pressure at various points of the airways

Let Q_0, Q_F, Q_E be the quantities of air entering the mine, passing the booster fan and reaching the working face respectively. Let k, k_1, k_2 be the efficiencies defined by

$$k = \frac{Q_E}{Q_0}, \quad k_1 = \frac{Q_F}{Q_0}, \quad k_2 = \frac{Q_E}{Q_F}, \quad \dots \dots \dots \dots \quad (5)$$

so that

$$k = k_1 k_2. \quad \dots \dots \dots \dots \dots \dots \quad (6)$$

Let Q be the quantity of air passing the point of the intake, distant l from the working face, where the pressure is P, and let δQ be the quantity lost in length δl of the intake where the pressure drops by δP from P.

3. EQUATIONS FOR THE OUTBYE SIDE OF THE BOOSTER FAN.

For flow in the airway through length δl we have

$$\delta P = r_1 \delta l Q^n, \quad \dots \dots \dots \dots \dots \dots \quad (7)$$

while for leakage through the barrier

$$\delta Q = \frac{2P - P_0}{r_2} \delta l. \quad \dots \dots \dots \dots \quad (8)$$

From (7) and (8) we obtain

$$\frac{dP}{dl} = r_1 Q^n, \quad \dots \dots \dots \dots \dots \dots \quad (9)$$

$$\frac{dQ}{dl} = \frac{2P - P_0}{r_2} \quad \dots \dots \dots \dots \dots \quad (10)$$

and hence

$$\frac{dQ}{dP} = \frac{2P - P_0}{r_1 r_2 Q^n}. \quad \dots \dots \dots \dots \dots \quad (11)$$

Separating variables and integrating from the booster fan to an arbitrary point outbye, we have

$$Q^{n+1} - Q_F{}^{n+1} = \frac{n+1}{r_1 r_2}(P - \tfrac{1}{2}P_0)^2, \quad \dots\dots\dots\dots \quad (12)$$

and for the complete section of the airway outbye of the booster fan

$$Q_0{}^{n+1} - Q_F{}^{n+1} = \frac{n+1}{4r_1 r_2}P_0{}^2. \quad \dots\dots\dots\dots \quad (13)$$

From (10) and (12) we have

$$\frac{dQ}{dl} = 2\left\{\frac{r_1}{r_2(n+1)}(Q^{n+1} - Q_F{}^{n+1})\right\}^{\frac{1}{2}}, \quad \dots\dots\dots\dots \quad (14)$$

which gives

$$\int_{Q_F}^{Q_0} \frac{dQ}{(Q^{n+1} - Q_F{}^{n+1})^{\frac{1}{2}}} = 2\left\{\frac{r_1}{r_2(n+1)}\right\}^{\frac{1}{2}} l_1. \quad \dots\dots\dots\dots \quad (15)$$

Now

$$\int_{Q_F}^{Q_0} \frac{dQ}{(Q^{n+1} - Q_F{}^{n+1})^{\frac{1}{2}}} = \int_{Q_F}^{Q_0} Q^{-\frac{n+1}{2}}\left\{1 - \left(\frac{Q_F}{Q}\right)^{n+1}\right\}^{-\frac{1}{2}} dQ.$$

$$\dots\dots\dots\dots\dots\dots \quad (16)$$

To evaluate this integral, put $\left(\dfrac{Q_F}{Q}\right)^{n+1} = t$ and we have

$$Q = Q_F t^{-\frac{1}{n+1}},$$

so that

$$dQ = -\frac{Q_F}{n+1} t^{-\frac{n+2}{n+1}} dt.$$

Hence, using (5), (16) may be written

$$\int_{Q_F}^{Q_0} \frac{dQ}{(Q^{n+1} - Q_F{}^{n+1})^{\frac{1}{2}}}$$

$$= -\frac{Q_F}{n+1}\int_1^{k_1{}^{n+1}} Q_F{}^{-\frac{n+1}{2}} t^{\frac{1}{2}}(1-t)^{-\frac{1}{2}}t^{-\frac{n+2}{n+1}} dt$$

$$= \frac{Q_F{}^{-\frac{n-1}{2}}}{n+1}\int_{k_1{}^{n+1}}^1 t^{-\frac{n+3}{2n+2}}(1-t)^{-\frac{1}{2}} dt$$

$$= \frac{Q_F{}^{-\frac{n-1}{2}}}{n+1}\left\{\int_0^1 t^{-\frac{n+3}{2n+2}}(1-t)^{-\frac{1}{2}} dt - \int_0^{k_1{}^{n+1}} t^{-\frac{n+3}{2n+2}}(1-t)^{-\frac{1}{2}} dt\right\}.$$

$$\dots\dots\dots\dots\dots\dots \quad (17)$$

The integrals on the right-hand side of (17) may be expressed in terms of beta functions and hypergeometric functions (Whittaker and Watson, 1946, p. 293). For

$$\int_0^1 t^{-\frac{n+3}{2n+2}}(1-t)^{-\frac{1}{2}} dt = B\left(\tfrac{1}{2},\ \frac{n+1}{2n+2}\right), \quad \dots\dots\dots \quad (18)$$

and, putting $k_1{}^{n+1}u=t$, we have

$$\int_0^{k_1{}^{n+1}} t^{-\frac{n+3}{2n+2}}(1-t)^{-\frac{1}{2}}dt$$

$$=\int_0^1 k_1{}^{-\frac{n+3}{2}}u^{-\frac{n+3}{2n+2}}(1-k_1{}^{n+1}u)^{-\frac{1}{2}}k_1{}^{n+1}du$$

$$=k_1{}^{\frac{n-1}{2}}\int_0^1 u^{-\frac{n+3}{2n+2}}(1-k_1{}^{n+1}u)^{-\frac{1}{2}}du$$

$$=k_1{}^{\frac{n-1}{2}}\frac{\Gamma\left(\dfrac{n-1}{2n+2}\right)\Gamma(1)}{\Gamma\left(\dfrac{3n+1}{2n+2}\right)}F\left(\tfrac{1}{2},\ \frac{n-1}{2n+2}\ ;\ \frac{3n+1}{2n+2}\ ;\ k_1{}^{n+1}\right)$$

$$=\frac{2n+2}{n-1}k_1{}^{\frac{n-1}{2}}F\left(\tfrac{1}{2},\ \frac{n-1}{2n+2}\ ;\ \frac{3n+1}{2n+2}\ ;\ k_1{}^{n+1}\right). \quad\dots\dots\dots\dots (19)$$

Hence, using (18) and (19), (17) now becomes

$$\int_{Q_F}^{Q_0}\frac{dQ}{(Q^{n+1}-Q_F{}^{n+1})^{\frac{1}{2}}}$$

$$=\frac{Q_F{}^{-\frac{n-1}{2}}}{n+1}B\left(\tfrac{1}{2},\ \frac{n-1}{2n+2}\right)-\frac{2Q_0{}^{-\frac{n-1}{2}}}{n-1}F\left(\tfrac{1}{2},\ \frac{n-1}{2n+2}\ ;\ \frac{3n+1}{2n+2}\ ;\ k_1{}^{n+1}\right).$$

$$\dots\dots\dots\dots\dots\dots (20)$$

Thus, combining (15) and (20), we have

$$(n-1)Q_F{}^{-\frac{n-1}{2}}\left\{\frac{r_1}{r_2(n+1)}\right\}^{\frac{1}{2}}l_1$$

$$=\frac{n-1}{2n+2}B\left(\tfrac{1}{2},\ \frac{n-1}{2n+2}\right)-k_1{}^{\frac{n-1}{2}}F\left(\tfrac{1}{2},\ \frac{n-1}{2n+2}\ ;\ \frac{3n+1}{2n+2}\ ;\ k_1{}^{n+1}\right).$$

$$\dots\dots\dots\dots\dots\dots (21)$$

4. Equations for the Inbye Side of the Booster Fan.

For flow in the airway inbye of the booster fan, we have as before

$$\frac{dP}{dl}=r_1Q^n, \quad\dots\dots\dots\dots\dots\dots (22)$$

and for leakage through the barrier

$$\frac{dQ}{dl}=\frac{2P-P_0+\alpha P_0}{r_2}. \quad\dots\dots\dots\dots (23)$$

Hence

$$\frac{dQ}{dP}=\frac{2P-P_0+\alpha P_0}{r_1r_2Q^n}. \quad\dots\dots\dots\dots (24)$$

Separating variables and integrating from the working face to an arbitrary point inbye of the booster fan we obtain

$$Q^{n+1} - Q_E{}^{n+1} = \frac{n+1}{r_1 r_2}(P - \tfrac{1}{2}P_0 + \tfrac{1}{2}\alpha P_0)^2, \quad \dots\dots\dots\dots \quad (25)$$

and for the complete section of the airway between the booster fan and the working face

$$Q_F{}^{n+1} - Q_E{}^{n+1} = \frac{n+1}{4r_1 r_2}\alpha^2 P_0{}^2. \quad \dots\dots\dots\dots\dots\dots \quad (26)$$

From (23) and (25) we have

$$\frac{dQ}{dl} = 2\left\{\frac{r_1}{r_2(n+1)}(Q^{n+1} - Q_E{}^{n+1})\right\}^{\frac{1}{2}}, \quad \dots\dots\dots\dots \quad (27)$$

which gives

$$\int_{Q_E}^{Q_F} \frac{dQ}{(Q^{n+1} - Q_E{}^{n+1})^{\frac{1}{2}}} = 2\left\{\frac{r_1}{r_2(n+1)}\right\}^{\frac{1}{2}} l_2. \quad \dots\dots\dots\dots \quad (28)$$

Hence, using (5), we get as before

$$(n-1)Q_E{}^{\frac{n-1}{2}}\left\{\frac{r_1}{r_2(n+1)}\right\}^{\frac{1}{2}} l_2$$

$$= \frac{n-1}{2n+2}B\left(\tfrac{1}{2}, \frac{n-1}{2n+2}\right) - k_2{}^{\frac{n-1}{2}}F\left(\tfrac{1}{2}, \frac{n+1}{2n+2}; \frac{3n+1}{2n+2}; k_2{}^{n+1}\right).$$
$$\dots\dots\dots\dots \quad (29)$$

5. The Complete Airway.

Using (6), and the fact that $\dfrac{R_1}{R_2} = \dfrac{r_1 L^2}{r_2}$, we have, on multiplying (21) by $k_2{}^{\frac{n-1}{2}}$ and adding to (29),

$$(n-1)\left\{\frac{R_1}{R_2(n+1)}\right\}^{\frac{1}{2}} Q_E{}^{\frac{n-1}{2}}$$

$$= \frac{n-1}{2n+2}B\left(\tfrac{1}{2}, \frac{n-1}{2n+2}\right) - k_2{}^{\frac{n-1}{2}}F\left(\tfrac{1}{2}, \frac{n-1}{2n+2}; \frac{3n+1}{2n+2}; k_2{}^{n+1}\right)$$

$$+ \frac{n-1}{2n+2}k_2{}^{\frac{n-1}{2}}B\left(\tfrac{1}{2}, \frac{n-1}{2n+2}\right) - k^{\frac{n-1}{2}}F\left(\tfrac{1}{2}, \frac{n-1}{2n+2}; \frac{3n+1}{2n+2}; k_1{}^{n+1}\right).$$
$$\dots\dots\dots\dots \quad (30)$$

Further, multiplying (21) by $k_2{}^{\frac{n-1}{2}}$ and dividing by (29), we get

$$\frac{l_1}{l_2} = \frac{\dfrac{n-1}{2n+2}k_2{}^{\frac{n-1}{2}}B\left(\tfrac{1}{2}, \dfrac{n-1}{2n+2}\right) - k^{\frac{n-1}{2}}F\left(\tfrac{1}{2}, \dfrac{n-1}{2n+2}; \dfrac{3n+1}{2n+2}; k_1{}^{n+1}\right)}{\dfrac{n-1}{2n+2}B\left(\tfrac{1}{2}, \dfrac{n-1}{2n+2}\right) - k_2{}^{\frac{n-1}{2}}F\left(\tfrac{1}{2}, \dfrac{n-1}{2n+2}; \dfrac{3n+1}{2n+2}; k_2{}^{n+1}\right)},$$
$$\dots\dots\dots\dots \quad (31)$$

which will be used to give the position of the booster fan.

We now introduce the total ventilating pressure **P**, defined by

$$\mathbf{P} = (1+\alpha)P_0. \quad \dots\dots\dots\dots\dots\dots (32)$$

For the complete airway we have, adding (13) and (26) and remembering that $R_1 R_2 = r_1 r_2$,

$$\frac{1+\alpha^2}{(1+\alpha)^2}\mathbf{P}^2 = \frac{4R_1 R_2}{n+1}(Q_0{}^{n+1} - Q_E{}^{n+1}). \quad \dots\dots\dots (33)$$

On dividing (13) by (33) and using the efficiencies defined by (5) we obtain

$$k_1{}^{n+1} = \frac{\alpha^2 + k^{n+1}}{1+\alpha^2}, \quad \dots\dots\dots\dots\dots (34)$$

which enables us to find k_1 when k and α are given.

6. MINIMUM LEAKAGE.

We assume that leakage losses will be reduced to a minimum when, for variations of α, a maximum face ventilation is achieved for a given value of the efficiency k of the system. All the variables concerned are functions of k and α. Thus if k is taken as fixed, derivatives with respect to α may be regarded as total derivatives.

Differentiating (34) with respect to α, we have, for constant k,

$$\frac{dk_1}{d\alpha} = \frac{2\alpha(1 - k^{n+1})}{(1+\alpha^2)^2(n+1)k_1{}^n}, \quad \dots\dots\dots\dots (35)$$

which can be simplified with the aid of (34) to give

$$\frac{dk_1}{d\alpha} = \frac{2\alpha(1 - k_1{}^{n+1})}{(1+\alpha^2)(n+1)k_1{}^n}. \quad \dots\dots\dots\dots (36)$$

From (6) we obtain

$$\frac{dk_2}{d\alpha} = -\frac{k_2}{k_1}\frac{dk_1}{d\alpha}. \quad \dots\dots\dots\dots\dots (37)$$

Using the result for differentiation of hypergeometric functions, viz.

$$\frac{d}{dz}F(a, b ;\ c ;\ z) = \frac{ab}{c}F(a+1, b+1 ;\ c+1 ;\ z), \quad \dots\dots\dots\dots (38)$$

we may now differentiate (30) with respect to α, so that for maximum Q_E, we obtain

$$-\frac{n+1}{3n+1}k_2{}^{n+1}F\left(\frac{3}{2}, \frac{3n+1}{2n+2} ;\ \frac{n+3}{n+2} ;\ k_2{}^{n+1}\right) + F\left(\frac{1}{2}, \frac{n-1}{2n+2} ;\ \frac{3n+1}{2n+2} ;\ k_2{}^{n+1}\right)$$

$$-\frac{n-1}{2n+2}B\left(\frac{1}{2}, \frac{n-1}{2n+2}\right) - \frac{n+1}{3n+1}k_1{}^{\frac{3n+1}{2}}F\left(\frac{3}{2}, \frac{3n+1}{2n+2} ;\ \frac{5n+3}{2n+2} ;\ k_1{}^{n+1}\right) = 0.$$

$$\dots\dots\dots\dots\dots\dots (39)$$

Applying (34) and (6) to this we obtain a relation between k and α, the solutions of which give the value of α, corresponding to a fixed value of the efficiency k, such that maximum face ventilation will be achieved.

7. METHOD OF CALCULATION.

In the former paper, equation (39) with $n = 2$ was solved for values of k between 0 and 1 at intervals of $0\cdot 1$ by a method of successive approximation. Thus for each value of k a value of α was found such that Q_E should be a maximum. Equation (30) was then used to find this value of Q_E.

In the present work n has been taken equal to $1 \cdot 9$, $1 \cdot 8$, $1 \cdot 7$ in turn, and the value of $(n-1)\left\{\dfrac{R_1}{R_2(n+1)}\right\}^{\frac{1}{2}} Q_E^{\frac{n-1}{2}}$ has been determined, using (30), for each value of k and various values of α in the neighbourhood of the value previously determined for the case when $n=2$. From these results the value of α giving maximum Q_E for each value of k has been determined graphically. The quantities Q_0 entering the mine and Q_F passing the booster fan follow immediately from (5) after calculating this maximum value of Q_E. The total ventilating pressure $\mathbf{P}$ is then found from (33) and the respective fan pressures P_0, αP_0 follow from (32). Finally the position of the booster fan is found by using (31).

The results of the computations for $n=2$, $n=1 \cdot 9$, $n=1 \cdot 8$, $n=1 \cdot 7$ are given in Tables I, II, III, IV respectively. The values corresponding to $k=0$ and $k=1$ have no practical significance, but are given to indicate theoretical limits.

TABLE I.

$n=2$.

k	α	$\dfrac{R_1}{R_2} Q_E$	$\dfrac{R_1}{R_2} Q_F$	$\dfrac{R_1}{R_2{}^2} P_0$	l_1/l_2
0	0	4·4	6·6	∞	2·65
0·1	0·05	3·3	4·9	190	1·75
0·2	0·13	2·5	3·7	49	1·34
0·3	0·24	2·0	2·9	16	1·20
0·4	0·35	1·6	2·2	7·7	1·13
0·5	0·45	1·2	1·6	3·6	1·09
0·6	0·57	0·94	1·2	1·7	1·06
0·7	0·67	0·67	0·79	0·74	1·04
0·8	0·78	0·43	0·48	0·25	1·02
0·9	0·88	0·21	0·22	0·05	1·01
1·0	1·00	0	0	0	1·00

TABLE II.

$n=1 \cdot 9$.

k	α	$\left(\dfrac{R_1}{R_2}\right)^{\frac{1 \cdot 0}{9}} Q_E$	$\left(\dfrac{R_1}{R_2}\right)^{\frac{1 \cdot 0}{9}} Q_F$	$\dfrac{R_1{}^{\frac{1 \cdot 0}{9}}}{R_2{}^{\frac{1 \cdot 9}{9}}} P_0$	l_1/l_2
0	0	6·2	9·5	∞	2·70
0·1	0·05	4·0	6·1	220	1·72
0·2	0·15	3·0	4·4	58	1·33
0·3	0·26	2·2	3·2	19	1·19
0·4	0·37	1·7	2·4	8·6	1·12
0·5	0·48	1·3	1·7	3·8	1·08
0·6	0·59	0·95	1·2	1·7	1·05
0·7	0·69	0·65	0·76	0·71	1·03
0·8	0·79	0·39	0·43	0·20	1·02
0·9	0·89	0·15	0·16	0·04	1·01
1·0	1·00	0	0	0	1·00

TABLE III.

$n = 1 \cdot 8$.

k	α	$\left(\dfrac{R_1}{R_2}\right)^{\frac{5}{4}} Q_E$	$\left(\dfrac{R_1}{R_2}\right)^{\frac{5}{4}} Q_F$	$\dfrac{R_1^{\frac{5}{4}}}{R_2^{\frac{9}{4}}} P_0$	l_1/l_2
0	0	9·7	15	∞	2·75
0·1	0·06	5·3	8·2	290	1·69
0·2	0·17	3·6	5·5	70	1·32
0·3	0·29	2·6	3·8	23	1·18
0·4	0·40	1·9	2·7	9·6	1·12
0·5	0·50	1·4	1·8	4·1	1·08
0·6	0·61	0·96	1·2	1·7	1·05
0·7	0·71	0·63	0·73	0·68	1·03
0·8	0·81	0·34	0·38	0·16	1·02
0·9	0·90	0·10	0·11	0·03	1·01
1·0	1·00	0	0	0	1·00

TABLE IV.

$n = 1 \cdot 7$.

k	α	$\left(\dfrac{R_1}{R_2}\right)^{\frac{1 \cdot 0}{7}} Q_E$	$\left(\dfrac{R_1}{R_2}\right)^{\frac{1 \cdot 0}{7}} Q_F$	$\dfrac{R_1^{\frac{1 \cdot 0}{7}}}{R_2^{\frac{1 \cdot 7}{7}}} P_0$	l_1/l_2
0	0	18	29	∞	2·85
0·1	0·07	7·5	12	400	1·66
0·2	0·18	4·7	7·3	86	1·31
0·3	0·31	3·1	4·7	27	1·17
0·4	0·42	2·2	3·2	11	1·11
0·5	0·53	1·5	2·0	4·6	1·07
0·6	0·64	0·98	1·2	1·7	1·05
0·7	0·73	0·60	0·71	0·64	1·03
0·8	0·82	0·29	0·32	0·13	1·02
0·9	0·91	0·07	0·07	0·02	1·01
1·0	1·00	0	0	0	1·00

The authors were unable to find tables giving values of the hypergeometric functions appropriate to this paper even though they are expressible in terms of incomplete beta functions. No tables of incomplete beta functions were available to cover the required range.

Where z does not exceed $0 \cdot 6$, the series expansion

$$F(a, b \; ; \; c \; ; \; z) = \frac{\Gamma(c)}{\Gamma(a)\,\Gamma(b)} \sum_{n=0}^{\infty} \frac{\Gamma(a+n)\,\Gamma(b+n)}{\Gamma(c+n)} \frac{z^n}{\Gamma(n+1)} \quad \text{.. (40)}$$

may be used to evaluate the function. However, if $0 \cdot 6 < z < 1$ the convergence of the series is very slow and it is more convenient to use the fact that (Whittaker and Watson, 1946, p. 291)

$$\Gamma(c-a)\,\Gamma(c-b)\,\Gamma(a)\,\Gamma(b)\,F(a, b \; ; \; c \; ; \; z)$$
$$= \Gamma(c)\,\Gamma(a)\,\Gamma(b)\,\Gamma(c-a-b)\,F(a, b \; ; \; a+b-c+1 \; ; \; 1-z)$$
$$+ \Gamma(c)\,\Gamma(c-a)\,\Gamma(c-b)\,\Gamma(a+b-c)(1+z)^{c-a-b}\,F(c-a, c-b \; ; \; c-a-b+1 \; ; \; 1-z).$$
$$\cdots\cdots\cdots\cdots \quad (41)$$

In the present case this reduces to

$$F\left(\tfrac{1}{2}, \frac{n-1}{2n+2}; \frac{3n+1}{2n+2}; z\right) = \frac{\Gamma\left(\frac{3n+1}{2n+2}\right)\Gamma(\tfrac{1}{2})}{\Gamma\left(\frac{n}{n+1}\right)} z^{-\frac{3n+1}{2n+2}}$$

$$-\frac{n-1}{n+1}(1-z)^{\frac{1}{2}}F\left(1, \frac{n}{n+1}; \frac{3}{2}; 1-z\right),$$

$$\dots \dots \dots \dots \dots (42)$$

and the hypergeometric function on the right-hand side of (42) may be readily evaluated by using the series expansion (40) for $0\cdot6 < z < 1$.

Towards the solution of (39) the calculation will be facilitated by using the relation (Whittaker and Watson, 1946, p. 296)

$$F(a+1, b+1; c+1; z) = \frac{c}{az}\{F(a, b+1; c; z) - F(a, b; c; z)\},$$

$$\dots \dots \dots \dots \dots (43)$$

which for our purposes reduces to

$$F\left(\frac{3}{2}, \frac{3n+1}{2n+2}; \frac{5n+3}{2n+2}; z\right)$$

$$= \frac{3n+1}{(n+1)z}\left\{(1-z)^{-\frac{1}{2}} - F\left(\tfrac{1}{2}, \frac{n-1}{2n+2}; \frac{3n+1}{2n+2}; z\right)\right\}. \quad \dots \dots (44)$$

Application of (44) to (39) gives

$$(1-k_2^{n+1})^{-\frac{1}{2}}$$

$$= \frac{n-1}{2n+2}B\left(\tfrac{1}{2}, \frac{n-1}{2n+2}\right) + k_1^{\frac{n-1}{2}}\left\{(1-k_1^{n+1})^{-\frac{1}{2}} - F\left(\tfrac{1}{2}, \frac{n-1}{2n+2}; \frac{3n+1}{2n+2}; k_1^{n+1}\right)\right\},$$

$$\dots \dots \dots \dots \dots (45)$$

from which k_2 may be expressed explicitly in terms of k_1. Using this equation and taking k_1 as the independent variable, Mr. I. L. Rose, of Newcastle University College, has constructed several charts giving values of the different variables for values of k and n. Rose's method does not involve successive approximation and hence is likely to give more accurate results than our method of calculation. We are indebted to Mr. Rose for allowing us to use his charts to check our tables and we have accordingly corrected some of the entries.

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A REFERENCE COLUMN FOR THE TERTIARY SEDIMENTS OF THE SOUTH AUSTRALIAN PORTION OF THE MURRAY BASIN

By N. H. Ludbrook.*

(Communicated by Dr. W. R. Browne.)

ABSTRACT.

A reference column has been established for the Tertiary sediments of the Murray Basin. The major portion of the Tertiary sequence is represented and seventeen rock units are recognized.

The preparation of a bulletin on underground water supplies in the Murray Basin in South Australia has necessitated a more precise understanding of the Tertiary stratigraphy of the Basin in the hope that some anomalous features of the hydrology may be shown to be stratigraphically controlled. Despite the large number of relatively shallow boreholes drilled, the stratigraphic relationships of the aquifers were known only in the broadest outline.

The stage has now been reached when the lithology and faunas of the various interdigitating sedimentary formations are sufficiently well known for a reference column to be established. It is inevitable that as more material becomes available and the task of describing the faunas is undertaken, parts of the sequence will have to be modified in detail.

In view of the economic interest attached to the new interpretation, and for the bearing it may have on the issues raised by recent papers of Raggatt and Crespin (1952, 1955) this outline has been prepared in anticipation of the more elaborate description of the rocks and their faunas which will follow as soon as practicable.

Formation names have been approved by the Committee for Stratigraphic Nomenclature of the South Australian Division of the Geological Society of Australia in accordance with the Australian Code of Stratigraphic Nomenclature. Almost all are new.

The Murray Basin offers particular opportunities for study in that the major portion of the Tertiary sequence in southern Australia is represented. Furthermore, there is an abundance of material available in continuous outcrop and in bore cuttings.

The succession follows a characteristic pattern in South Australia of Eocene paralic sediments discontinuously overlain by normal marine limestones, marls and clays of Oligocene-Miocene age. The paralic facies is known almost entirely from subsurface material, but the marine facies is well exposed in the cliffs of the River Murray and on the western margin of the Basin where transgressive and regressive elements may be recognized. Their equivalents encountered in bores form an apparently continuous mid-Tertiary succession in deeper

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* Department of Mines, Adelaide ; published with the permission of the Acting Director of Mines.

parts of the Basin to the north-east in the general vicinity of the Murray River towards the Victorian border.   Sedimentation in the late-Tertiary is regressive and estuarine.

The reference column is shown diagrammatically in Table I.

TABLE I.

Series	Stage	Group	Formation
Pliocene	"Kalimnan"		Norwest Bend Formation
Upper Miocene	"Cheltenhamian"		Loxton Sands
	unnamed		Bookpurnong Beds
	? "Bairnsdalian"		Pata Limestone
Lower Miocene	"Batesfordian"	Murray Group	Morgan — Cadell Lens — Limestone
			Finniss Clay
	"Longfordian"		Mannum Formation
Oligocene	"Janjukian"	Glenelg Group	Naracoorte Member — Ettrick Marls — Gambier Limestone — Compton Conglomerate
Upper Eocene	unnamed	Buccleuch Group	C - clay B - sands, limestone Buccleuch Beds A - limestone marl
	unnamed		
Upper to Middle Eocene	Undifferentiated	Knight Group	Moorlands Coal Measures Undifferentiated sands, gravels, clays and siltstones

(A) PARALIC SEDIMENTS.

(1) *Unnamed Sediments of the Knight Group.*

The oldest Tertiary beds so far recognized in the South Australian portion of the Basin are a series of sands, gravels, clays and carbonaceous silts with intermittent marine intercalations, the equivalent, in part at least, of the Dartmoor Formation (Sprigg and Boutakoff, 1953).   These have not been studied in detail, but on stratigraphic and palynological evidence are believed to be of Middle to Upper Eocene age.   With the exception of 10 feet of gravel overlain by 3½ feet of clay exposed in Knight's quarry, Section 718, Hundred of

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Blanche, they are not known in outcrop in South Australia. They are of the order of 500 feet thick in the northern portion of the Basin, thickening to over 4,000 feet in the Gambier Sunklands in the south, where they overlie Mesozoic non-marine sediments, possibly mostly of Cretaceous age.

(2) *Moorlands Coal Measures.*

The brown coal deposits of Moorlands most recently described by McGarry (1953) were developed in an area of bedrock highs probably in the later stages of the paralic sequence.

(3) *Buccleuch Group.*

A minor marine transgression in the Upper Eocene produced a thin series of limestones, sands and clays typically developed in County Buccleuch, where, unless they have been cut off by bedrock highs, they are entered in bores in the hundreds of Coneybeer, Roby, Peake and Sherlock, where erosion during the Pleistocene appears to have removed most of the mid-Tertiary cover. These are the Buccleuch Beds which at this stage are not formally named individually.

The lowest beds (A), which are apparently lenticular, comprise 50 feet of glauconitic marl with a rich microfauna including *Cibicides pseudoconvexus* Parr, *Glabratella crassa* Dorreen, *Globigerina mexicana* Cushman, *Globigerinoides index* Finlay, *Gümbelina rugosa* Parr, *Lamarckina novozealandica* Dorreen, and *Asterigerina adelaidensis* (Howchin), and abundant radiolaria. The marl is overlain by a white bryozoal limestone up to 100 feet thick, physically resembling the Gambier Limestone, with *Cibicides pseudoconvexus* Parr, *Heronallenia pusilla* Parr, *Globigerina mexicana* Cushman, *Globigerinoides index* Finlay, *Gümbelina rugosa* Parr, *Asterigerina* cf. *lornensis* Finlay, and a large ornate species of *Crespinella.*

Bed (B), a useful aquifer in the area, consists of incoherent grey-brown sands with thin limestone bands. The limestones carry the important zonal echinoid *Australanthus longianus* (Gregory), hitherto known from the Tortachilla Limestones of the Willunga Basin and from limestones of Upper Eocene age on Kangaroo Island and in the Eucla Basin. The sands are generally rich in bryozoa derived from the limestone of beds (A). The associated microfauna is dominated by *Cibicides pseudoconvexus* Parr, *C. umbonifer* Parr, *Sherbornina atkinsoni* Chapman and *Crespinina kingscotensis* Wade among the larger species. McGarry's Marine Sequence I (McGarry, 1953, p. 86) covers this interval.

Overlying bed (B) is a grey-brown carbonaceous clay, bed (C), also with an assemblage of small foraminifera occurring elsewhere in the Upper Eocene or early Oligocene. This is McGarry's Marine Sequence II.

Coonalpyn No. 2 Bore, Hundred of Coneybeer, Section 56, is chosen as standard subsurface section for these beds, which were penetrated between 208 and 388 feet.

No published stage names are at present available for correlating this group of beds which are believed to be synchronous with Eocene sediments in the Johanna River area, Victoria.

(B) NORMAL MARINE SEQUENCE.

The Eocene freshwater to brackish sequence was followed by an active marine transgression with a complete change of facies.

(4) *Compton Conglomerate.*

The base of the marine sequence is marked by a ferruginous conglomerate 1½ feet thick in Knight's Quarry, Section 718, Hundred of Blanche, where it overlies a mottled clay of the Knight Group with marked stratigraphic dis-

continuity. The Conglomerate, or its lithological equivalents, persists over considerable distances and is generally from 10 to 30 feet thick. It may overlie Buccleuch Beds or rest directly on the sands and clays of the Knight Group. It grades upward into the Gambier Limestone or its equivalents.

(5) *Gambier Limestone.*

The formation first described as the Mount Gambier limestone from Portland in Victoria (Woods, 1867) is almost universally known in South Australia as the Gambier Limestone. A decision of the Stratigraphic Nomenclature Committee is required to unify the terminology.

The limestone is a highly porous even-textured aggregate of bryozoa with a characteristic megafauna and a " Janjukian " microfauna with abundant *Victoriella plecte.* The occurrence of *Victoriella plecte* is important. The species has a wide geographical distribution in South Australia from Canopus Bore in the north to the limestone at Point Turton on Yorke Peninsula in the west, also assumed to be " Janjukian ". Its presence must sometimes be treated with a certain amount of caution as its sturdy test renders it favourable to mechanical concentration by natural agencies. It is quite abundant in some Pleistocene sediments containing reworked Gambier Limestone and contaminates the surface of Knight clays underlying the Gambier Limestone in Knight's Quarry.

(6) *Naracoorte Limestone Member.*

A thin lenticular limestone overlies Gambier Limestone immediately to the east of Naracoorte, where it is worked in three quarries on the Kanawinka Fault Scarp. It is typically exposed in A. James and Sons quarry as a rather rubbly highly fossiliferous leached limestone (coquinite) separated probably by a diastem only from the even-textured Gambier Limestone below. Neither the megafauna, with *Cyprœa* cf. *dorsata* Tate, *Chlamys gambierensis* Woods, *Chlamys incertus* Woods, *Aturia australis* McCoy, *Cellepora gambierensis* Woods, nor the microfauna dominated by *Operculina victoriensis* Chapman and Parr and *Carpenteria rotaliformis* Chapman and Crespin, nor the physical characters of the limestone are regarded as warranting status as a separate formation from the Gambier Limestone.

(7) *Ettrick Marls.*

In the Hundreds of Ettrick, Seymour, Peake and Roby in the western part of the Basin the Gambier Limestone is replaced by a series of highly glauconitic marls and sandy marls, with *Massilina torquayensis* (Chapman) and other " Janjukian " species. These are here named the Ettrick Marls, the standard subsurface section of which is designated as Bore 2 Hundred Ettrick, Section 21, where the Marls occur from 210–280 feet. They are usually from 70 to 100 feet thick, are marked at the base by the equivalent of the Compton Conglomerate, and are overlain by the Mannum Formation. McGarry (p. 86) includes them in his Marine Sequence III.

On stratigraphical and faunal evidence the Gambier and Naracoorte Limestones and the Ettrick Marls are believed to be of Oligocene age. All the beds ·between the base of the Compton Conglomerate and the top of the Naracoorte Limestone should be included within the *Glenelg Group* (Sprigg and Boutakoff, 1953). The Nelson sandstones of this group almost certainly occur in South Australia, but lack definition at present.

The younger limestone clays and marly limestones from the base of the Mannum Formation to the top of the Gordon Limestone are here named the *Murray Group.*

(8) *Mannum Formation.*

Exposed in the township of Mannum and extensively developed in the district are " raggy " calcareous sandstones and sandy limestones comprising the Mannum Formation, a richly fossiliferous littoral coquinite crowded with remains of the echinoid known as *Lovenia forbesi.* The formation is a markedly transgressive element on the western margin of the Murray Basin. It has been divided on lithological and faunal grounds into a lower and upper member, the faunas of which have been listed in manuscript. The microfauna of the upper member is marked by the entry of *Austrotrillina howchini* (Schlumberger) and *Planorbulinella plana* (Heron-Allen and Earland) at the base in addition to an assemblage of small foraminifera dominated by as yet undescribed species of *Nonion, Crespinella* and *Sherbornina* (=*Cycloloculina*) and poorly preserved small species occurring in the lower member.

A conspicuous break in sedimentation representing a local regression or diastem occurs at the top of the Formation, which is of the order of 100 feet thick, 62 feet being exposed at the type section at the Mannum Pumping Station, Section 519, Hundred of Finniss.

(9) *Finniss Clay.*

Fifteen feet of poorly fossiliferous mottled blue-grey, green and brown marine gypseous clay rest on the surface of the Mannum Formation at the type section at the Pumping Station. The fauna is impoverished and characterized by the absence of megafossils, but the foraminifera include *Amphistegina lessonii* d'Orbigny, *Eponides præcinctus* Karrer for the first time, with *Austrotrillina howchini, Calcarina verriculata* (Howchin and Parr), *Operculina victoriensis* and other less important species.

In the upper two-thirds the clay is thinly interbedded with the Morgan Limestone, into which it passes conformably.

(10) *Morgan Limestone.*

The Morgan Limestone forms the base of the cliffs of the River Murray practically throughout the whole of its course from above Overland Corner downstream to below Blanchetown. It is a highly bryozoal, fine and generally even-grained sandy limestone, frequently gypseous and sometimes marly. It is typically exposed at the section measured by Tate (1885) four miles south of Morgan, Section G, Hundred of Cadell, the lower member being represented in the lowest 43 feet 6 inches ; the upper member, 26 feet 2 inches thick, overlies the lenticular Cadell Marl in the type section but elsewhere directly overlies the lower member.

The Morgan Limestone carries a " Batesfordian " microfauna dominated by *Operculina victoriensis, Gypsina howchini* Chapman, *Gypsina globulus* Reuss, *Amphistegina lessonii, Elphidium* sp. cf. *papillosum* Cushman. The fauna with *Cycloclypeus victoriensis* recorded by Crespin (1944) from a sample collected by F. A. Cudmore gives little cause for doubt that this was taken from the Morgan Limestone at the type section. Although it has not so far been found at the type locality, *Lepidocyclina*, which has been found only in recent years in South Australia, has a wide distribution in the Morgan Limestone from as far north as Waikerie and Loxton to Caloote, $4\frac{1}{2}$ miles south of Mannum, where it is fairly abundant and visible on weathered surfaces. Its most westerly known occurrence is on Yorke Peninsula in the limestone on Section 388, Hundred of Kulpara, two miles north of Melton.

(11) *Cadell Marl Lens.*

This richly fossiliferous blue-grey sandy marl is exposed at the type section of the Morgan Limestone as a lens in the Limestone about 300 yards long and 22 feet thick. It is the classical " Blue Marl " from which most of the mollusca

described by Tate from the " Gastropod Bed " of his " Middle Murravian " were taken. *Turritella murrayana* is extremely abundant.

The marl is fairly extensive in the Morgan-Renmark area. Its fauna is also apparently Batesfordian, with *Austrotrillina howchini*, currently believed to be of Lower Miocene age.

(12) *Pata Limestone.*

In the Loxton area a porous grey bryozoal limestone from 15 to 80 feet thick is encountered at depths from 120 to 220 feet overlying marly equivalents of the Morgan Limestone. The microfauna appears to be that described as " Balcombian " from localities on Port Phillip Bay (Chapman, Parr and Collins, 1934). It contains open sea foraminifera, with *Cibicides victoriensis* Chapman, Parr and Collins and *Orbulina universa* d'Orbigny making their first appearance. It has not yet been recognized in outcrop, but extends as far south as Pinnaroo. Drainage Shaft 18 Loxton, Hundred of Gordon, Section 377, is designated standard subsurface section for the Pata Limestone, which was penetrated between 126 and 182 feet, and the overlying Bookpurnong Beds, penetrated between 78 and 126 feet depth.

(13) *Bookpurnong Beds.*

These are red-green and green micaceous and glauconitic marls up to 100 feet thick, extensively developed throughout the north-easterly portion of the Basin. The Bookpurnong fauna is of particular interest in that it represents a biofacies similar to that of the Pliocene Dry Creek Sands of the Adelaide Basin. There seems no doubt that these are the beds from which Tate obtained his " Murray Desert " fossils, many species of which occur in the Dry Creek Sands. Both Pliocene and Miocene elements are contained in the Bookpurnong fauna, the age of which must be determined on the basis of the stratigraphic relationship of the beds to the overlying sediments. On this evidence a late Miocene age is suggested.

No suitable exposure of the beds is available as a type section ; they are probably partly exposed downstream from Loxton when the river level is low.

(14) *Loxton Sands.*

The Loxton Sands, 50 feet of which are exposed in the type section on the southern side of the Loxton Pumping Station, Section 138, Hundred of Gordon, are cross-bedded, coarse, gritty micaceous sands and silty sands with shelly bands showing secondary calcification near the base. The formation is widely developed in the more northerly part of the Basin. It is subject to local change of facies and is of economic interest as a building " freestone " at Waikerie and Cadell. The shelly and foraminiferal faunas are similar to those at the type locality for the Cheltenhamian at Beaumaris, Victoria. Formerly regarded as Lower Pliocene, this stage is at present placed in the Upper Miocene.

(15) *Norwest Bend Formation.*

A period of emergence followed the deposition of the Loxton Sands succeeded by estuarine conditions favouring the development of thick oyster beds which discordantly overlie the older marine sediments. At the type section at Norwest Bend Head Station the oyster beds are represented by 28 feet of sandy limestone and calcareous sands with abundant *Ostrea sturtiana*. A useful associated molluscan fauna with *Neotrigonia howitti* and *Glycymeris convexa*, suggesting a Kalimnan age, occurs there.

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ABSTRACT OF PROCEEDINGS.

4th April, 1956.

The seven hundred and nineteenth Annual and General Monthly Meeting was held in the Hall of Science House, Sydney, at 7.45 p.m.

The President, Dr. M. R. Lemberg, F.R.S., was in the chair. Forty-eight members and visitors were present. The minutes of the previous meeting were taken as read.

The following death was announced : Henry Maxwell Harris, a member since 1949.

The certificate of one candidate for admission as an ordinary member was read for the first time.

Awards : It was announced that the Society's awards were as follows : The Society's Medal for 1955 was made to Dr. W. G. Woolnough. The James Cook Medal for 1955 was made to Professor A. P. Elkin. The Edgeworth David Medal for 1955 was made to Dr. H. B. S. Womersly. The Clarke Medal for 1956 was made to Professor O. W. Tiegs, F.R.S.

Annual Report : The Annual Report of the Council was presented and adopted.

Financial Statement : The Financial Statement was presented and adopted.

Election of Auditors : Messrs. Horley and Horley were re-elected as Auditors to the Society for 1956–57.

Bound Volume 88 : It was announced that this volume was now available and that it would be appreciated if members living in the metropolitan area would call at the office and pick up their copies.

Resignations : It was announced that the following persons had resigned from membership of the Society : J. H. Caldwell, H. T. C. Howard, W. Johnson, H. A. McKenzie, H. N. S. Schafer and J. O. Zehnder.

Library.—The following donations were received : parts of periodicals 681, purchased parts 132, back numbers 135, books 15.

Papers.—The following paper was read by title only : '' Occulations observed at Sydney Obseratory during 1955 '', by K. P. Sims, B.Sc.

The following were elected office bearers for 1956–57 :

President.—F. D. McCarthy, Dip.Anthr.

Vice-Presidents.—R. C. L. Bosworth, M.Sc., D.Sc. (Adel.), Ph.D. (Camb.), F.A.C.I., F.Inst.P. ; Ida A. Browne, D.Sc. ; M. R. Lemberg, D.Phil., F.R.S.; C. J. Magee, D.Sc.Agr. (Syd.), M.Sc. (Wis.).

Hon. Secretaries.—J. L. Griffith, B.A., M.Sc., Dip.Ed.; F. N. Hanlon, B.Sc.

Hon. Treasurer.—H. A. J. Donegan, M.Sc., A.S.T.C., A.R.A.C.I.

Members of Council.—Rev. T. N. Burke-Gaffney, S.J.; F. W. Booker, M.Sc., Ph.D.; J. A. Dulhunty, D.Sc.; F. P. J. Dwyer, D.Sc.; H. O. Fletcher ; A. F. A. Harper, M.Sc., A.Inst. P.; A. C. Higgs ; J. S. Proud, B.E. (mining) ; Griffith Taylor, D.Sc., B.E., B.A.; H. W. Wood, M.Sc., A.Inst.P., F.R.A.S.

The retiring President, Dr. M. R. Lemberg, F.R.S., presented his Presidential Address entitled " Cellular Respiration ".

At the conclusion of the Address the Chairman welcomed Mr. F. D. McCarthy to the Presidential Chair.

2nd May, 1956.

The seven hundred and twentieth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. D. McCarthy, was in the Chair. Twenty-five members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificate of one candidate for admission as an ordinary member was read for the first time.

The certificate of one candidate was read for the second time and the following person was elected a member of the Society : Stuart Duncan McPhee.

Library.—The following donations were received : parts of periodicals 220 ; purchased parts 20, back numbers 12.

Papers.—The following paper was presented : "The South Australian Earthquake of 1939, March 26 " by K. E. Bullen and B. A. Bolt. The following papers were read by title only : " 6–Covalent Complexes with Acetylacetone and Bivalent Metals ", by F. P. Dwyer and A. M. Sargeson. " The Volatile Oil of *Baeckea Citriodora* sp. nov.", by H. H. G. McKern, F. R. Morrison and A. R. Penfold.

The evening was devoted to a symposium on " Electron Microscopy " and the following addresses were given : " The Electron Microscope and Its application ", by Mr. V. A. Pickles of the School of Applied Chemistry, N.S.W. University of Technology. " Some Contributions of the Electron Microscope in Problems of Cell Structure ", by Dr. F. V. Mercer of the Department of Botany, the University of Sydney.

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6th June, 1956.

The seven hundred and twenty-first General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. D. McCarthy, was in the Chair. Eighty-five members and visitors were present. The minutes of the previous meeting were taken as read.

The following death was announced : Walter Fitzmaurice Burfitt, a member since 1898.

The certificate of one candidate for admission as an ordinary member was read for the first time.

The certificate of one candidate was read for the second time and the following person was elected a member of the Society : Cedric Arthur Hawkins.

It was announced that the following had resigned their membership of the Society : Mrs. Norma Brown and V. B. Rao.

It was also announced that the following had been admitted as Associates : Mrs. Elizabeth S. Donegan and Mrs. Elsie A. Griffith.

Library.—The following donations were received : parts of periodicals 225 ; purchased parts 24 ; back numbers 6.

Papers.—The following papers were read by title only : " The Epicentre of the Adelaide Earthquake of 1954, March 1 ", by B. A. Bolt. (Communicated by Professor K. E. Bullen.) " Further Notes on Ordovician Formations of Central New South Wales ", by N. C. Stevens. " Conversions Between Equatorial Coordinates and Standard Coordinates on Photographic Plates ", by Harley Wood. " Minor Planets Observed at Sydney Observatory During 1955 ", by W. H. Robertson.

The evening was devoted to an address on " Problems of Antarctic Research ", by Mr. Phillip Law, Director, Antarctic Division, Department of External Affairs, Melbourne, with an introduction by Professor Griffith Taylor, who was a member of Scott's Expedition to the Antarctic, 1910–1912. By courtesy of the N.S.W. Film Council, the film " Blue Ice " was screened.

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4th July, 1956.

The seven hundred and twenty-second General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. D. McCarthy, was in the chair. Fifty-four members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificate of one candidate for admission as an ordinary member was read for the first time.

The certificate of one candidate was read for the second time and the following person was elected a member of the Society : James Bernard Croft.

Library.—The following donations were received : parts of periodicals 187 ; purchased parts 30 ; books 8 ; back numbers 16.

Papers.—The following papers were read by title only : " The Stratigraphy and Petrology of the Narrabeen Group in the Grose River District ", by K. A. W. Crook. " On the Association of Albitites and Soda Aplites with Potash Granites in the Precambrian and Older Palaeozoic of Australia ", by Germaine A. Joplin.

The evening was devoted to a symposium on " The Utilization of Radio-Isotopes " and the following addresses were given : " Isotopes—Their Nature, Their Production and Measurement ", by Dr. J. Green, School of Chemistry, N.S.W. University of Technology. " The Application of Radio-Active Isotopes in Medicine ", by Dr. A. G. Basser, Institute of Medical Research, Royal North Shore Hospital. " Recent Developments on Isotopes in U.K. and U.S.A.", by Dr. J. N. Gregory, Australian Atomic Energy Commission.

1st August, 1956.

The seven hundred and twenty-third General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. D. McCarthy, was in the chair. Fifty-two members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificates of four candidates for admission as ordinary members were read for the first time.

The certificate of one candidate was read for the second time and the following person was elected a member of the Society : Bruce Alan Bolt.

Library.—The following donations were received : parts of periodicals 256 ; purchased parts 14 ; books 2.

Papers.—The following papers were read by title only : " Observations on Mt. Gibraltar ", by Robert Stevens. " A Study of Layered Sedimentary Materials in the Riverine Plain, New South Wales ", by C. A. Hawkins and P. H. Walker.

The evening was devoted to a symposium on " Blood Grouping " and the following addresses were given : " Nature of Human Blood Groups ", by Professor P. M. de Burgh, Department of Bacteriology, University of Sydney. " The Practical Application of the Human Blood Groups ", by Dr. R. J. Walsh, Director, Blood Transfusion Service, Sydney. " The Blood Groups and Anthropology ", by Miss Olga Kooptzoff, Serologist, Blood Transfusion Service, Sydney.

5th September, 1956.

The seven hundred and twenty-fourth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

Dr. M. R. Lemberg, F.R.S., a Vice-President was in the chair. Thirty-two members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificate of one candidate for admission as an ordinary member was read for the first time.

The certificates of four candidates were read for the second time and the following persons were elected members of the Society : George Petersen, Raymond Arthur Priddle, David John Thomson and Patrick Hilton Walker.

The Hon. Secretary reported that the Council, having in mind the financial state of the Society, had decided the Society should relinquish the office space on the ground floor. The Society's office would now be situated in the library, on the first floor.

The Chairman stated that in his opinion the removal would not only save the Society a considerable sum of money but would also be a distinct improvement since it would induce members to make use of the library frequently. He invited members to inspect the new arrangements at the termination of the meeting. A number of members and visitors took advantage of the invitation.

It was announced that Dr. M. R. Lemberg, F.R.S., a Vice-President of the Society, had recently been elected a Foreign Member of the Heidelberg Akademie de Wissenschaften Math.-naturw. Klasse.

It was also announced that Dr. F. P. Dwyer, a member of Council, had been appointed to the Chair of Organic Chemistry at the University of Pennsylvania.

It was announced that the following had resigned his membership of the Society : Frank K. Rickwood.

The following name has been erased from the List of Members and his indebtedness " written off " : Alan J. Mortlock.

Library.—The following donations were received : parts of periodicals 230 ; purchased parts 18 ; books 3.

Papers.—The following papers were read by title only : " Erosion Surfaces around Armidale, N.S.W.", by A. H. Voisey, D.Sc. " Refraction in Photographic Astrometry ", by Harley Wood.

The evening was devoted to the Commemoration of Great Scientists and the following addresses were given : " N. I. Lobatschevsky and the Fall of Euclidean Geometry ", by Mr. J. L. Griffith, Senior Lecturer in Mathematics, N.S.W. University of Technology. " Avogadro and the Number of Molecules in a Gas ", by Dr. F. P. J. Dwyer, Senior Lecturer in Chemistry, University of Sydney. " Edmond Halley ", by Mr. Harley Wood, Government Astronomer, Sydney Observatory.

3rd October, 1956.

The seven hundred and twenty-fifth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. D. McCarthy, was in the chair. Thirty-one members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificates of three candidates for admission as ordinary members were read for the first time.

The certificate of one candidate was read for the second time and the following person was elected a member of the Society : Simon Jacques Prokhovnik.

Library.—The following accessions have been entered : parts of periodicals 197 ; purchased parts 18 ; books 3.

Paper.—The following paper was read by title only : " A Note on Two Dimensional Fourier Transforms ", by J. L. Griffith, B.A., M.Sc.

The evening was devoted to a symposium on Radiophysics and the following addresses were given : " The Ionosphere—A Graveyard for Expert Predictions ", by Dr. J. L. Pawsey, C.S.I.R.O., Division of Radiophysics. " Vacuum and Semi-Conductor in Electronics ", by Dr. L. W. Davies, C.S.I.R.O., Division of Radiophysics. " Radio Surveys the Milky Way ", by Mr. F. J. Kerr, C.S.I.R.O., Division of Radiophysics. " The Nature of Nervous Conduction ", by Professor P. O. Bishop, Department of Physiology, University of Sydney.

7th November, 1956.

The seven hundred and twenty-sixth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. D. McCarthy, was in the chair. Twenty-one members and visitors were present.

A vote for election to membership of the Society could not be taken, as the number of members present at the meeting was insufficient for the necessary quorum.

The following announcements were made : That Dr. L. E. Lyons, a member of the Society, had been awarded a Fulbright travel grant to take up a research appointment at Harvard University.

Members were notified that, in future, the " Journal and Proceedings " of the Royal Society of New South Wales will be posted to members in quarterly parts as issued. The Society is willing to recommend the name of binder on request.

Library.—The following accessions have been entered : parts of periodicals, 150.

Papers.—The following papers were read by abstract only : " The Third Dissociation Constant of the Tris-acetylacetone Complexes with Bivalent Metals ", by F. P. Dwyer, D.Sc., and A. M. Sargeson, B.Sc. ; " Clay Minerals in Some Hawkesbury Sandstones ", by F. C. Loughnan and H. G. Golding.

The evening was devoted to a symposium on " Problems of Pasture Development in Australia ", and the following addresses were given : " Plant Nutritional Aspects of Pasture Improvement ", by Mr. Fred Cradock of the Department of Agriculture, Sydney ; " Biological Problems in Pasture Establishment ", by Mr. Kevin Marshall, of the Department of Agriculture, Sydney ; " Impact of Research on Pasture Development in Australia ", by Mr. W. T. Atkinson, of the Department of Agriculture, Sydney.

5th December, 1956.

The seven hundred and twenty-seventh General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. D. McCarthy, was in the chair. Twenty-six members and visitors were present. The minutes of the previous meeting were read and confirmed.

The certificate of one candidate for admission as an ordinary member was read for the first time.

The certificates of three candidates were read for the second time, and the following persons were elected members of the Society : Arnold Walter Fleischmann, Thomas Benjamin Huw Jenkins, Maxwell Herbert McKay.

Library.—The following accessions have been entered in the catalogue : parts of periodicals, 88.

Papers.—The following papers were presented : " The Volatile Oil of *Bœckea citriodora* sp. nov.", by H. H. G. McKern, F. R. Morrison and A. R. Penfold ; " The Epicentre of the Adelaide Earthquake of 1954 March 1 ", by B. A. Bolt ; " A Study of Layered Sedimentary Materials in the Riverine Plain, New South Wales ", by C. A. Hawkins and P. H. Walker ; " Refraction in Photographic Astrometry ", by Harley Wood ; " A Note on Two-Dimensional Fourier Transforms ", by J. L. Griffith ; " A Note on the Generalization of Weber's Transform ", by **J. L. Griffith** ; " Efficient Use of a Booster Fan in Mine Ventilation ", by M. H. McKay, **A. H. Low** and A. Keane ; " A Reference Column for the Tertiary Sediments of the South Australian Portion of the Murray Basin ", by Mrs. N. H. Ludbrook (communicated by Dr. W. R. Browne).

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NOTICE.

THE ROYAL SOCIETY of New South Wales originated in 1821 as the "Philosophical Society of Australasia"; after an interval of inactivity, it was resuscitated in 1850, under the name of the "Australian Philosophical Society", by which title it was known until 1856, when the name was changed to the "Philosophical Society of New South Wales"; in 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, it assumed its present title, and was incorporated by Act of the Parliament of New South Wales in 1881.

TO AUTHORS.

Particulars regarding the preparation of manuscripts of papers for publication in the Society's Journal are to be found in the "Guide to Authors", which is obtainable on application to the Honorary Secretaries of the Society.

The previous volumes and separate parts of the *Journal and Proceedings* may be obtained at the Society's Rooms.

The Library and Reading Room of the Society at Science House, Gloucester and Essex Streets, Sydney, is available for the use of members on week-days, 10 a.m. to 12 noon and 2 p.m. to 4 p.m.

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